SHORT SPAN SUSPENSION BRIDGES

Highway Loads H-15

Thesis for the Degree of C. E.

Eric Edmund Bottoms

1935

THESIS

Bridges, Suspension
Title

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INTRODUCTION OR PREFACE

The main reason for choosing this subject may be traced back to certain advice which Dr. J. A. L. Waddell so generously bestowed to the young and aspiring engineers in his Magnus Opus. "Bridge Engineering" and its companion volume. "Economics of Bridge Work". His writings have been the inspiration for this attempt to obtain a means of estimating accurately and quickly the quantities of material in superstructures, substructures and approaches of short span suspension bridges designed for light highway loadings.

It is believed that a light highway suspension bridge is a most satisfactory way of connecting farms, estates, factories and communities that are just across the river from the main highway. A suspension bridge is of scenic beauty in any locality. It is quickly erected; the comparatively light weight of material used, making heavy expensive equipment unnecessary.

Eric E. Bottoms

Chicago, Illinois June, 1935

SHORT SPAN SUSPENSION BRIDGES

The original design of the suspension bridge is one of the simplest. Our ancestors stretched ropes or chains across a river or ravine, and laid a floor directly upon them. From that time to the present, there has been a gradual increase in the development and design of the suspension bridge. In recent years there has been a noticeable increase in number of short span suspension bridges built. Although few have been built, they have shown, in many cases, new and uncommon expedients. This trend is important as designers are more apt to incorporate new and novel ideas in small or less costly bridges, than in more expensive ones, thus, the art of suspension bridge design will be accelerated.

Many engineers would propose a suspension bridge in place of a simple span if they could, without complete detail design, compare the relative costs. This paper intends to show a method and means to secure the quantities of materials for all parts of short span suspension bridges by an easy and accurate method. Unit prices are purposely omitted due to the variation in cost of material and erection in the various parts of the country.

Let us look back in history and trace the development of the suspension bridge. The first bridge engineers were our arboreal ancestors who formed living chains of their own bodies from tree to tree and bank to bank over which weaker members of their tribes passed. Natives of tropical jungle countries often times fashioned crude suspension bridges by using twisted vines and matted fibers.

Xerxes is credited with building a small suspension bridge in crossing the Hellespont during his invasion of Greece in 480 B. C. It is said to have consisted of ropes on which beams were laid transversely and suspended between ships.

All early suspension bridges were made of planks laid directly on chains. The first of this type was built in China, 65 A. D.

Although the suspension bridge is the oldest and most picturesque type of all bridges, and after completion, is the safest structure because of its simplicity, known to bridge engineers, the modern type is an American invention, and its greatest development has been in this country. James Finlay built the first regular modern suspension bridge in 1796, and obtained patents on this type of bridge from the United States Government. Hand forged chains were used on all Finlay's bridges, the largest of which was the bridge across the Schuyskill River, built in Philadelphia in 1809. The total span of 306 feet was made up of two individual spans of 153 feet each with an intermediate pier. This bridge collapsed in 1811 from the weight of an excessive load of cattle. It was replaced with another bridge, which also collapsed, under a load of snow and ice. A third, a foot bridge, was opened in June, 1816, with a span of 408 feet and a width of 18 inches; the cables were composed of six three-eighths inch wires, and a wooden floor without stiffening. This also failed under a load of snow and ice. It was, however, the first wire suspension bridge in any country.

The most famous of the old chain bridges designed under the Finley patent was the one built in 1810 across the Merrimac River, three miles from Newburyport, Massachusetts. It had a span of 244 feet, and was 40 feet above the water. It had two roadways fifteen feet wide and "was strong enough to allow for the passage of horses and carriages, whatever their speed. The railing was stout and strong, which contributed much to the stiffness of the floor". It is of interest to note that in 1909, a hundred years later, the original chains were replaced with parallel wire cables conforming with the present day practice. The balance of the bridge was also replaced without changing the appearance of the structure, so it would retain its original outline.

The Menai Strait Bridge at Bangor, North Wales, between the islands of Anglesey and Carnarvonshire was built in 1826 by Mr. Thomas Telford and is still in use today. It consists of a central span 580 feet long, a side span of 280 feet, four fifty-foot stone arches at one end and three at the other, a total strength of 1,710 feet. The floor, 30 feet in width, contains two roadways and a four foot walk, is supported by sixteen main cables arranged in four sets vertically above one another, one set at each side of each roadway. The Masonry towers are 152 feet high and 29 feet thick at the level of the roadway. Each chain consists of five iron bars, 3 1/4 inches by 1 inch, 10 feet long, united by 8x16 inch links and 3 inch pins. When Telford planned this bridge, he investigated the major forces by means of models. It was unquestionably a remarkable accomplishment in bridge engineering, not only because of its unprecedented span, but because of many other unusual features, its splendid conception and its ingenious erection.

Von Mites built a chain bridge over the Danube Canal with a span of 354 feet in 1828. Cables were flat bars of open hearth steel. This was the first use of steel for bridge building in any country.

M. Vicat in 1831 wove the first cables in place during the erection of a suspension bridge across the Rhone. Previous to this, wire cables were woven on the ground and then lifted.

In 1860, the Von Mites bridge was taken down and replaced with another designed by Schnirch having a span of 225 feet. It was noted for being the first, and at that time, the only railroad suspension bridge in Europe.

John A. Roebling started on his long career of bridge building with the Pittsburgh Aqueduct in 1844. This was composed of seven individual spans, each 162 feet long and supported by two seven-inch cables. Each cable was composed of seven strands made up of 236 wires 0.148 inch diameter, totaling 1,652 wires in each cable.

A combined railway and highway bridge built by Roebling across the Niagara River in 1854, which had been thought an impossible feat, was the first long span, 821 feet, to be constructed with stiffening trusses insuring a rigid floor. Stiffening trusses had been used a few years before on a small suspension bridge over the Kentucky River at Frankfort, Kentucky, but its span was only 400 feet. The stiffening truss was developed because of the excessive vibration on the floor and the possible danger of being overturned by heavy winds. Roebling introduced the aerial spinning process on the Niagara River Bridge. It consisted of pulling loop after loop of single wire across the river, from anchorage to anchorage over the towers by means of a travelling wheel. The wires were laid up in strands, which upon completion, were compacted together into a cylindrical cable and tightly wrapped with wire. This method has been used on all large suspension bridges erected since.

Another bridge was built across the Niagara River a short distance below the Falls in 1867 by Samuel Keefer of Ottawa. It had a main span of 1, 260 feet. The cables were supported on wooden towers.

The famous Brooklyn Bridge built in 1883 was made possible by drawn steel wire. All previous suspension bridge cables were fabricated from wire drawn from charcoal iron, and for the first time on any bridge, the cables were protected with a layer of galvanized wire.

In 1928, the Camden-Philadelphia Bridge was completed. It had a center span of 1,750 feet, the longest at that time. The side spans are each 716 feet long. Its 128.5 foot width is taken up by a 57 foot roadway, 6 lanes, and 4 tracks for rapid transit trains. There are also two ten-foot wide elevated footwalks. This whole roadway is supported by two wire cables each thirty inches in diameter on steel towers 380 feet above the water.

The George Washington Bridge across the Hudson River at Fort Lee, having a main span of 3,500 feet, was completed in 1931, forty-eight years later after the completion of the Brooklyn Bridge. It represents more than a hundred-per-cent increase in main span length over both the Brooklyn and Camden-Philadelphia Bridges.

The accompanying graph plate No. 1 may be of interest as it shows the increase of main span lengths from 1816 when the Schuylkill Bridge was built by Finlay up to and including the Golden-Gate Bridge which is scheduled for completion early in 1938. This graph clearly shows that the Cincinnati Bridge over the Ohio River was the forerunner of the Brooklyn Bridge, and that the Brooklyn Bridge held the record until its span was excedded by five feet when the Williamsburg Bridge was built in 1903, twenty years later. The line connecting the peaks is interesting.

In the lower right hand corner of Plate No. 1 are several modern short span highway bridges which indicate the revived interest in suspension bridges for short spans. They will be discussed in turn.

The Rondout Creek Bridge at Kingston, New York, was opened to the traffic in 1922. It was the first of the so-called "Modern Short Span Suspension Bridges" with a main span of 705 feet. The roadway is supported by two nine inch cables each made up of seven strands, each composed of 282 galvanized wires 0.195 inches in diameter. Due to the steepness of the side span cables, it was necessary to add extra strands from the tower to the anchorage to take up the larger load. The strength of the main span cables is 6,320 tons each and for the side spans, 6,803 tons.

It is clear that the construction of this bridge incited the interest of many engineers and highway departments because five years later the General Ulysses S. Grant Bridge was built at Portsmouth, Ohio, to be followed by seven or more spans under 1,007 feet in the next seven years.

The General U. S. Grant Bridge opened in 1927 has a main span of 700 feet. The designers calculated the stresses and sections by the common elastic theory, and then assumed a reduction of ten per-cent for deflection correction, because they lacked an adequate theory for exact analysis of continous spans. They believed a greater reduction would be justified but they had no way of determining the proper amount. Had Dr. Steinman's theories been available at that time, a reduction of eighteen per-cent would have been available.

The Grand Mere Bridge, Quebec, was opened in 1929. At that time, it was the longest structure, 949 foot span, of its type. The cable ropes were cut and socketed in the shop to exact dimensions. The roadway is eighteen feet wide and designed for H-15 loadings or 60 lbs. per square foot on the road and 12 lbs. per square foot on the sidewalks, which corresponds to the A-20 loading of the Canadian Engineering Standards Association. Wind loads of 35 and 25 lbs. were used on the unloaded and loaded portions of the span. The cables were designed for a dead load of 1,450 lbs. and a live load of 1,152 lbs. per linear foot of bridge. The main span is made up of 39 panels, 24 feet, 4 inches each. The backstays, unloaded, are straight.

The Maumee River Bridge, Toledo, Ohio, built in 1929-31 has five traffic lanes and two sidewalks. The main span is 785 feet. The roadway is supported by two 13 1/4 inch (before wrapping) cables composed of 19,3 inch strands, The individual wires are .195 inch in diameter. The strands are made up of single wires laid in a parallel formation and the strands are laid parallel in the cables. The towers are 220 feet high. The suspenders are 1 5/8 inch in diameter.

The San Rafael Bridge, completed in 1933 over the Rio Yaque del Norte, near Mao, in San Domingo, has a main span of 450 feet. It has two lanes nine feet wide designed for H-15 loadings, This bridge is noticeable for three special features:--- (1) The floor is of interlocking steel channels, (2) The main cables are prestressed parallel strands of open type construction, (3) The main saddles are built into the tower thereby placing the centerline of the cables at the intersection of the main tower members and eliminating the usual eccentric wind loadings at the top of the towers. This method brings all resultant forces to a common point, permitting a clean cut tower top devoid of artificialities. The towers are of the fixed flexible type, 57 feet, 11 inches high. The stiffening truss, modified Warren, with a 1 to 75 ratio, has 30 panels, each 14 feet, 11 3/4 inches long.

The San Domingo Republic completed another short span suspension bridge in 1934. This bridge, which spans the Higuamo River near San Pedro de Macoris, is called the Mamfis Bridge. The central span is 654 feet long and the side spans are 196 feet long. The design of this bridge is also for H-15 loading. The same three features incorporated in the San Rafael Bridge are used. Most of the suspenders are of prestressed cable. The main cables are made up of nine strands in open construction. This open type of construction imparts to the uninitiated, added strength.

The Civil Conservation Corps in the state of California in 1934 constructed with their own personnel, two short span suspension bridges, one across the Kalamath at Happy Camp of 300 feet, the other across the Sacramento River at Sims of 100 feet. Both have stiffening trusses, modified Warren type, and are designed according to the Government 15 ton loading, which provides for a string of 15 ton trucks following each other at reasonable intervals.

The stages of development of the suspension bridge is clearly divided into four parts: (1) construction, (2) analysis, (3) economics, and (4) esthetics.

In early construction the bridge was composed of a light platform, unstiffened, suspended from a cable made up of chains, eye-bars, single wires, wire ropes, and spun strands, the loads passing directly from the floor into the cable. When the bridges constructed in this fashion became unsatisfactory for concentrated loads, the builders constructed heavy railings, the forerunner of the stiffening truss. Later the roadway was made up of a series of simple spans, panel length, which were supported by means of suspenders to the main cable.

As the science of bridge building developed and the designers expanded their knowledge of analysis, the simple trusses were made continous through the supporting points and the stiffening trusses extended from one tower to the other. Elastic and deflection theories were expounded with the trend towards the deflection theory and designing of the bridges by exact methods eliminating all indeterminate stresses.

Economical bridge construction is made up of three parts: (1) adequate strength and capacity (correct designing), (2) durability and minimum cost of maintenance, (3) flexibility and movability. These three points establish the usefulness and the value of the bridge, and not its cost of construction - the cost of a bridge and the value have no relation to each other.

Adequate strength and capacity of a bridge are merely the result of correct designing and construction. Experience has demonstrated the need for designing the modern bridge to include provisions for the future increase of its strength and capacity. These provisions can be made with a small increase in the first cost. If we knew the future demands of transportation, such precautions would not be necessary. Increased traffic involves weight and volume.

Durability and minimum cost of maintenance of a bridge depends entirely upon that type of construction and kinds of materials incorporated into the structure and method of protection.

Adaptability does not necessarily apply to a suspension bridge for few have been taken apart and reconstructed elsewhere, but if we design with true economy this must be considered. This is one advantage that the open type of cable construction, as used in the San Rafael Bridge, has over those with cables spun and compacted in place, as were the cables in the Maumee Bridge.

On the fourth or esthetic stage, bridge engineers have barely entered. The professional obligation of making bridges structures of beauty is being realized more and more. The following factors are

1. The background is taken into consideration. For an example, the towers of St. John's Bridge in Oregon are designed to harmonize with the background of hills covered with evergreen trees.

2. The design adopted is a unit; the parts of which, must be in proportion.

3. Emphasis should be placed upon the function of the structure, and it should be ornamented only with that in view. Put in another view, this step on the composition is intended to dramatize the important features of the design.

The best appearing bridge is always the one in which the engineering solution is correct, with the architectural treatment serving merely to emphasize the important features of design. Any design of true beauty must necessarily originate with the engineer, leaving the architect only in the role of collaborator, contributing to the attractiveness of the engineer's creation.

Bridges have two functions: To satisfy the demands of traffic, and to have an acceptable appearance. The engineer who fails to design for these two requisites does not perform a complete service.

Before discussing the design or method used in computing the various curves that appear later, it is well to notice the theories advocated by the engineers at the top of the profession.

Dr. J. A. L. Waddell states in his "Economics of Bridge Work", "The theory of stress determination adopted was the approximate method given in Johnson, Bryan and Turneaure's 'Modern Framed Structures', Part 2, instead of the older method of Dr. William H. Burr, which, for convenience and simplicity was taken as standard by the author in writing Chapter 27 of 'Bridge Engineering'". The results of the two theories do not differ greatly, especially for bridges with end trusses anchored, but the latter theory requires a little less metal.

Roebling carefully worked out stresses for the Brooklyn Bridge from facts that he himself had observed. His first suspension structure, the Pittsburgh Aqueduct was without precedent, but because he was confident that his figures were right, he willingly took the risk. Since that time, many theories have been expounded.

Professor J. Melan in his "Eiserne Bogenbrücken und Hängebrücken" devised a deflection theory, which is applicable to designs having either continous or hinged trusses. It yields lower moments and shears and consequently savings up to 65 per-cent, in the weight of the metal of the stiffening truss. This theory is applicable to continous and multiple span design, as well as to the single span, two-hinged type. Steinman's general conclusion is that the continuous type of suspension bridge offers advantages over the two-hinged type for spans under 1,000 feet when designed for highway loading, and longer spans when designed for railroad loadings.

Johnson, Bryan and Turneaure's formulae are based on Melan's theories. Their exact method takes into consideration deflection, which, as stated above, cuts down the moment and hence the cost.

The theory later used in computing various curves is that of Johnson, Bryan and Turneaure's: the type of bridge is the two-hinged stiffening truss with unloaded backstays.

The live loads used are in accord with the A. R. E. A. Specification for highway bridges (Plate No. 2). All the data obtained tends to show that it is not necessary to consider the actual distribution of live loads to the cable when uniform loads are used. - - The unit weights taken for various dead loads are as follows: - - -

1. Creosoted lumber	4.5 to 5	lbs.	per	board	foot.
2. Hardwood (Oak)	4.25	"	"	"	"
3. Yellow Pine	3.75	"	"	"	"
4. Soft Wood (White Pine)	2.75	"	"	"	"
5. Concrete (Regular)	150.	"	"	cubic	"

6.	Concrete (Haydite)	110.	lbs. per cubic foot
7.	Ashphalt pavement - 2 inches thick	1?0.	" " square "
8.	Steel	490.	lbs. per cubic "
9.	Earth	100.	" " " "
10.	Snow (Compacted)	50.	" " " "

Various types of cables have been used, described as follows:—

1. Cables made up of a number of individual wires all laying parallel in the finished cable.

2. Those made up of a number of twisted wire strands, the strands laying parallel in the finished cable.

3. Those made up of a number of wire ropes, the ropes laying parallel in the finished cable.

They differ in these units;—

1. Wire (Individual)
2. Strands (Wires twisted into a rope)
3. Ropes (Strands twisted into a rope)

They may be more simply named:—

1. Parallel wire cables (usually spun in place)
2. Parallel strand cables.
3. Parallel rope cables.

Twisted strands or rope strands should be distinguished from wire ropes. A rope is made up by twisting a number of rope strands around a central strand, a substantial loss in the magnitude of "E" (modulus of elasticity) results from this additional operation.

The cables used on the San Rafael Bridge are prestressed, parallel strand, using open type of construction. The open construction gives an impression of a larger cable (about 30%) larger, and increases the appearance. The individual strands are far enough apart to permit ready inspection at all times, and to allow painting. Wrapping costs are saved. The strands are in layers in the saddles, with zinc fillers separating the layers. With this arrangement, strand bearing pressures are negligible, for no strand bears on the saddle with the pressure other than its own, whereas, in a closed cable, the lower strands are subject to a compressive load from all upper strands.

Nearly all suspension bridges have followed the precedent set by the Brooklyn Bridge in using parallel wire cables, with wires of about 0.2 square inch cross section. Although the diameter of wire used has remained almost constant, the quality of wire has steadily improved, as shown by the following tabulation giving the ultimate strength of wires used in representative bridges.

Bridge	Tons per square inch.
Niagara	58
Brooklyn	80
Williamsburg	90
Manhattan	96
Delaware	100
George Washington	104
Golden Gate	104
San Rafael	112

This comparision shows the economy of prestressing bridge cables. (The San Rafael Bridge cables were prestressed, as noted above).

On the same bridges, the stiffening trusses have been gradually reduced in depth and weight. A tabulation of this will be given later.

The time needed for spinning the parallel wire cables has decreased in the past years.

Brooklyn Bridge,	1883,	3,600 tons	in 21 months
Manhattan Bridge,	1909,	6,400 "	" 4 "
George Washington Bridge,	1931,	28,100 "	" 10 "

The weight freely suspended between towers has increased according to the span length, the time of erection has also varied.

Menai Straits Bridge,	650 tons
Brooklyn Bridge,	8,120 "
George Washington Bridge,	68,300 "

The George Washington Bridge was constructed in one-third the time that it took to construct the Brooklyn Bridge. The Brooklyn Bridge took twice as long as the Menai Straits Bridge to construct.

For the St. Johns Bridge in Portland, Oregon, the specifications called for twisted strand cables, as an alternative to the parallel wire cable design. As received, the bids showed a savings of $42,000 by adopting the twisted strand design. Moreover, this proposal announced an expected saving of two months in the time of completion of the bridge, this time being made possible by dispensing with the construction of foot bridges, and by shortening the time required for cable stringing. The diameter of these cables was 16 1/2 inch. Port Oxford Cedar was used for fillers. The wrapping wire was No. 9 soft annealed double galvanized wire.

Dr. Waddell states in his "Economics of Bridge Work", page 265, "The selection of the versed sine for the cables is a matter of economic importance. Increasing it reduces the sectional area of the cables and backstays, but augments slightly their lengths: it adds to the height and weight of tower columns and their bracing. On the other hand, it affects a slight savings in mass and cost of anchorages due to the reduction of overturning moment that is caused by the diminuation of stress in the backstays. Experience has shown that the depth of catenary equal to one-ninth of the span will usually give the most satisfactory results: but there is no hard and fast **rule** about this, and it is permissable to use any depth between the limits of on-eighth and one-tenth of the span".

However, for all practiable purposes, when the loads are to be considered uniform, the main cable may be taken as a parabola.

The length of the cable between tower saddles may be computed by:—

$$L = l + \frac{8d^2}{3l}$$

The back stays having no sag.

$L_s = K \sec B.$
L = Cable length between towers.
l = Horizontal distance between towers.
d = Sag in feet.
f = Ratio of sag - d/l.
L_s = Cable length for backstays.
K = Horizontal distance anchorage to tower.
B = Angle of backstay with horizontal.

There is a great opportunity for study in the design of economic anchorages. There are three main causes to be considered: - (1) Is the foundation to be on bed rock, (2) on piles, (3) clay or similiar material without piling. If bed rock is close to the surface, it will be wise to use it, but otherwise it will be more economic to put in a shallow anchorage either on piling or by spreading the base. The main economic expedient in so far as practiable, is to concentrate the weight at the rear of the anchorage and the spread of the surface at the front. This tends to increase the resisting moment against and to reduce the intensity of bearing at the toe. This means that it is economic, therefore, to make the anchorage low and narrow in front, and high in the rear. It may be one of several such buttresses, instead of one solid block of concrete. The toes may be joined to increase bearing value and the backs joined by a wall to increase its weights. In general, the economic choice is shaped more or less like a wedge.

The towers of the Brooklyn Bridge are of massive masonry and because this was the first large bridge, many engineers imitated it closely to have their designs accepted. The towers of the George Washington Bridge are designed to be covered with masonry at a later date, however, their present rugged beauty is due to the true design without a thought to beauty. It would be a shame if their honest designs should be hidden by a false front of cut stone.

The towers of the San Rafael Bridge have fixed column type of towers of steel, 57 feet 11 inches high with a batter of 21 inches. These towers are securely anchored to the main pier concrete. The stiffness factor may be described as follows:- A 734 lb. pull horizontally will deflect the column one inch, no vertical load considered. The determination of the stiffness factor under varying loads is essential in arriving at unstressed lengths and proper adjustments of cable strands.

Dr. Steinman's design of the St. John's Bridge towers is different expedient. The towers have vertical legs to carry the direct loads of the cable in conjunction with batter legs for bracing and stability, with either straight or batter legs alone, it is difficult to secure a pleasing affect. In one case the tower appears heavy, the other, - it assumes an awkward angularity. The combination is most satisfying. These towers are of the fixed flexible type.

The most economical type of towers are those of the fixed flexible type with vertical columns and batter legs with the saddles recessed into the column to pass all stresses through a common point.

The main pier substructure is commonly of mass concrete either carried down to rock or with a spread base supported on piles. In some cases, with extremely short spans, it may be practical to rely on spreading the base alone. The pier may either be of one solid mass, or, upon solid substrata in two parts, one under each tower leg. The most economical for small spans is solid concrete with a spread base upon piles. Local conditions are the deciding factor.

The depth of the stiffening trusses has gradually been reduced. An indication of the respective depth ratio is given by the following table:-

Bridge	Date	Ratio
Williamsburg	1903	1 to 40
Manhattan	1909	1 to 60
Bear Mountain.	1924	1 to 63
Delaware River	1926	1 to 63
Ambassador	1928	1 to 84
Grand' Mere.	1929	1 to 78
St. John	1931	1 to 67
Maysville.	1931	1 to 75
George Washington.	1931	1 to 120*
Golden Gate.	1931	1 to 168

* This ratio obtains when the lower deck is built, at present time there is no stiffening truss.

The general tendency both in the United States and abroad has been towards a rigid stiffening system, and the text books and many modern treatises on suspension bridges had confined themselves entirely to that system and to the elastic theory, without respect to span length, dead weight of the bridge, or character of the traffic.

The designer of the George Washington Bridge, Dr. D. B. Steinman, says "The permissability of an almost flexible system in the case of the completed bridge, - that is, - with rapid transit trains running over the bridge on the lower deck or an entirely flexible system in case the bridge carries only vehicular traffic on the upper deck, was not obvious to the writer at the inception of his studies.

"Extensive studies convinced the writer that for long span suspension bridges, a rigid system was not necessary. He was also familiar with the fact that by the application of the correct or so-called "deflection theory" as distinguished from "elastic theory" to a more or less flexible system, material economics can be affected.

"This is inherently due to the stiffening affect of the dead load, which affect is ignored in the so-called "elastic theory". The latter fact had been pointed out by various writers, notably Prof. Melan of Vienna, Austria. It had also been proved by the application of a modified deflection theory by Leon S. Moisseiff to the design of the Manhattan and Delaware River Bridges.

"The dead load resists the live load deformation of the cable polygon and, because of its great magnitude offers ample stiffening affect".

The foregoing discussion is applicable to long span bridges, however, it shows that in general the tendency is for short span suspension bridges to have a rigid stiffening system. A good average ratio of depth of stiffening truss to the main span for spans up to 1,000 feet is 1 to 65. This ratio will give an economic distribution of metal.

The floor system on suspension bridges is no different from the conventional floor system consisting of wearing surface, stringers, floor beams and lateral stiffening.

An interesting experiment was tried on the San Rafael Bridge. The flooring consists of interlocking steel channels, placed alternately up and down and covered with a mineraled surface asphalt plank, it has a total weight of 45 lbs. per square foot. of roadway area. The channels are laid at right angles to the stringers to which they are plug welded. This type of floor permits the omission of the usual diagonal members of a wind system. In affect, it is a plate girder with the floor as the web.

There are various types of approaches: - the simple and economical type being the trestle and viaduct. If esthetics or local conditions demand, short spans: through or deck, supported by piers or rocker bents, with the truss the same depth of the stiffening truss, come next in economic consideration. The least economic is to suspend the approaches from the backstays because:-

1. Far greater weight of the material required for the stiffening trusses and hangers as compared with that for a trestle approach.

2. Far greater cost of anchorages due to the large lever arm for the overturning moment, the cable pull being horizontal and applied near the elevation of the floor.

The only case in which it is economic to suspend the approach from the backstays is when there is deep water beneath that is required for navigation. If the water is deep and is not required for navigation, the economic choice is a series of deck spans, of as nearly as may be, economic length. Economic length being determined by the cost per linear foot of superstructure and substructure taken together.

After considering the aforementioned subjects and the judiciously application of formula and adhering to the best engineering practice, many computations have been made and the results plotted on plates 2 to 18 inclusive. Various designs which were selected as typical, and used as a basis for this work are shown on five plates, A to F inclusive.

An attempt was made to select a typical situation from which to estimate the quantities of materials necessary for a modern short span suspension bridge withan H-15 highway loading. Using this setting, a problem has been set up and worked out. Notations are shown on the computation forms which plate was consulted for that particular part or item.

It is the writer's belief that short span suspension bridges will be utilized more and more in coming years and that an accurate system of preliminary estimating as presented here will be of great use to the average engineer who is not a specialist in suspension bridge design.

THE END

No. 6 Sheet No. 1

Highway #42 Bridge over Sam Canyon

SPECIFICATION OF Bridge

Type of bridge Suspension

Width of road 20ft LOADING H15 C-C trusses 22ft.

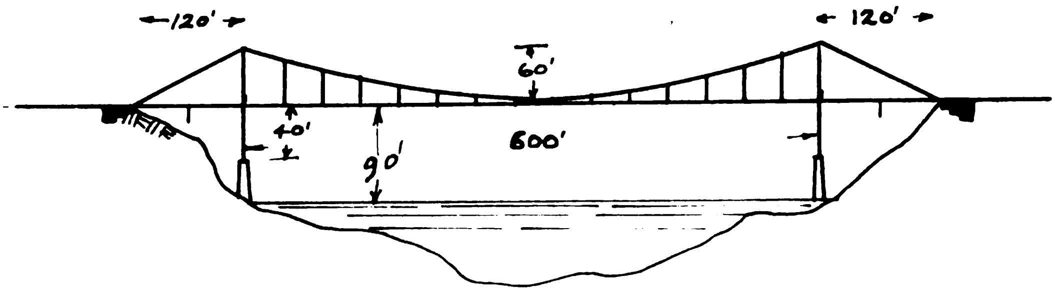
Span-C-C towers 600 feet Vertical clearance 90 feet.

Type of foundation Concrete piers on piles.

Approach spans 2 spans at 120 feet.

Approaches Natural grades.

Remarks Hangers on 30 foot centers. Earth pressure allowable for anchorages is 7000 lbs per sq. foot. Test piles show allowable loads of 20 tons for each 9 sq. feet allowed to a pile.



PROBLEM

Item *Main Span* Sheet No. *2*

Total load on cables, less cables per lineal foot of main span.- in pounds.

Live Load (plate 2)	56 X 20	1120	pounds
Impact (plate 2)	3 X 20	60	"
Concrete roadway slab. (plate 12)	6" Haydite	1000	"
Metal in floor system. (plate 5)	13.5 X 22	297	"
Metal in stiffening truss. (plate 7)	21.5 X 2 X 1	43	"
Average length of hangers. (plate 8)	20.5 feet.		
Weight of cable hangers.	2 X 20.5/30 X 2	4	"
Miscellaneous metal.	lump sum	30	"
TOTAL LOAD PER FOOT (A)		2554	"

Total load per foot on one cable

One half item (A)	1277	pounds
Assumed weight per foot of 1 cable	72	"
Total weight on 1 cable	1349	"

Use a cable weighing *72* pounds per foot.
plate 10

PROBLEM.

ITEM *Main Span.* Sheet No. 3

TOTAL WEIGHT OF MATERIAL

Floor system	297 x 600 =	187,200	pounds.
Stiffening trusses	43 x 600	25,800	"
Miscellaneous metal	30 x 600 =	18,000	"
Hanger cable	4 x 600 =	2,400	"
Main cable, including backstays from plate 9	880 x 72 x 2 =	126,720	"
Concrete slab	1000 x 600	600,000	"
TOTAL WEIGHT (B)		960,320	pounds
Weight per lineal foot	960,320/600 (C)	1600+	"

ITEM *Approach Spans.*

Span 2 @ 120' Type *Light Load (H-15)*

Structural metal			pounds.
plate no. 14	132,000 x 2	264,000	"
Concrete slab plate 12	1500 x 120'	180,000	"
TOTAL WEIGHT (D)		444,000	pounds.

ITEM *Towers*

Load on tower.	itemized below		pounds.
Live load, main span	1120 x 600	672,000	"
Live load, approach span	76 x 20 x 120'	172,400	"
Impact, main span	60 x 600	36,000	"
Impact, approach span	13.5 x 20 x 120'	32,400	"
Weight main span	(B)	960,320	"
Weight approach span	(D)	444,000	"
TOTAL WEIGHT		2,317,120	pounds.

PROBLEM

ITEM *Towers Continued* Sheet No. *4*

Total divided by 2 for weight on one tower

2,317,120 ÷ 2 = *1,158,560* pounds.

Steel per lineal foot plate 15. *410* "

Total metal in one tower *410 X 100* *41,000* "

TOTAL FOR TWO TOWERS *82,000* "

ITEM *Piers*

Weight on one tower. *1,158,560* pounds.

Weight of one tower. *41,000* "

TOTAL WEIGHT ON ONE PIER *1,199,560* "

From plate 16 read.–

Piles *43* @ *25'* *1050* feet

Cofferdam *85* "

Concrete *150* cu. yds.

ITEM *Anchorages*

Weight per lineal foot on cables including cables (c) *1600* pounds.

Tension on anchorage (plate 17) *1,350,000* "

Concrete in one anchorage (plate 18) *320* cu. yds.

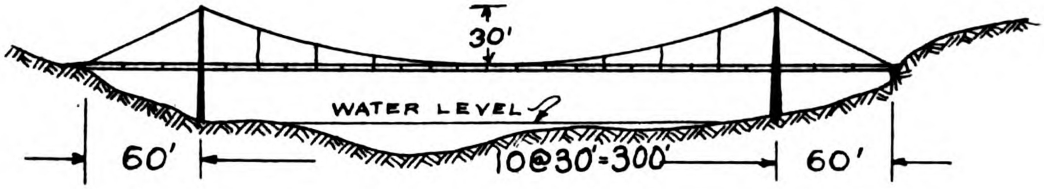
TOTAL CONCRETE *320 X 2 =* *640* " "

PROBLEM.

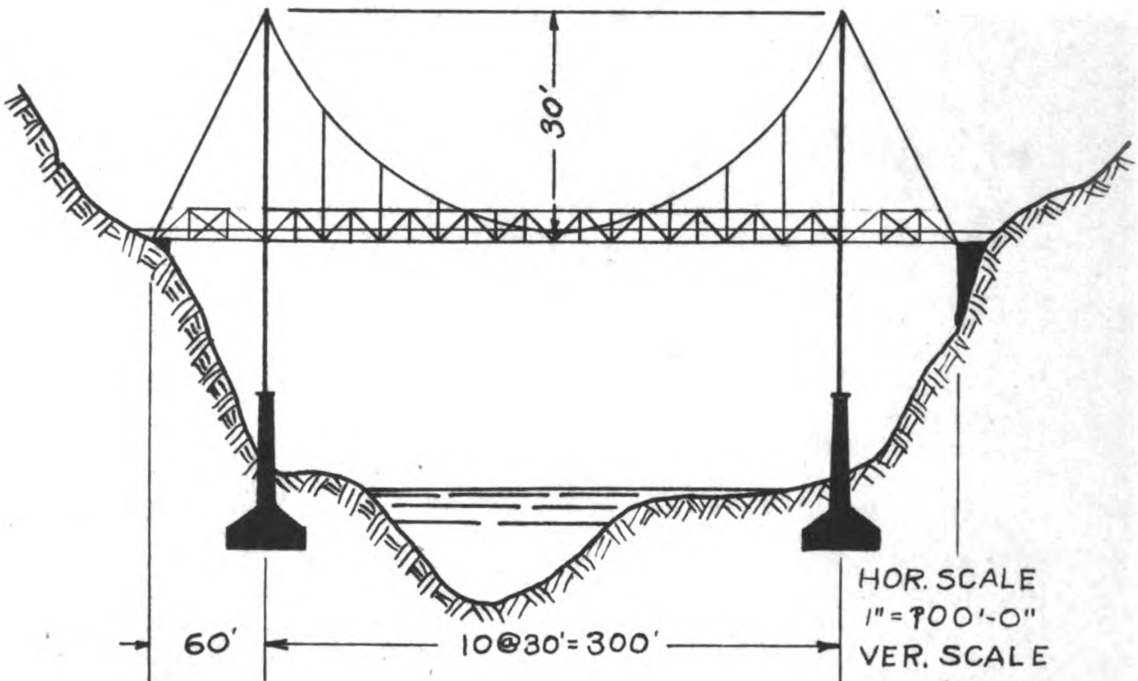
ITEM *Summary and Costs* Sheet No. 5.

Main cable	126,720	lb@		
Main span.				
Floor system.	187,200	lb.@		
Stiffening truss.	25,800	lb@		
Miscellaneous metal.	18,000	lb@		
Hanger cable	2,400	lb.@		
Concrete slab (Haydite)	600,000	lb.@		
Approach span.				
Structural metal	264,000	lb.@		
Concrete slab	180,000	lb.@		
Tower steel	82,000	lb.@		
Piers				
Piles	1,050	ft.@		
Cofferdam	85	ft.@		
Concrete *including rein. steel*	150	C.Y.@		
TOTAL				
Percentage for engineering				
TOTAL COST				

PROBLEM.

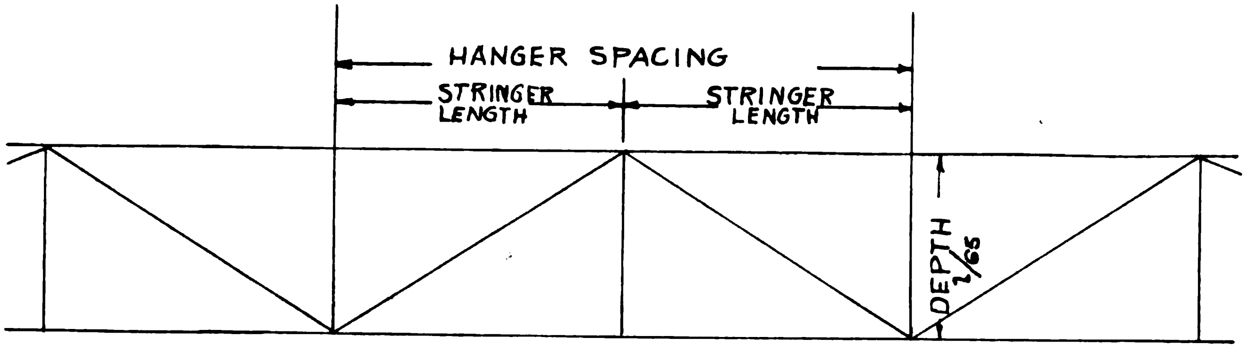


NATURAL
SCALE 1"=100'

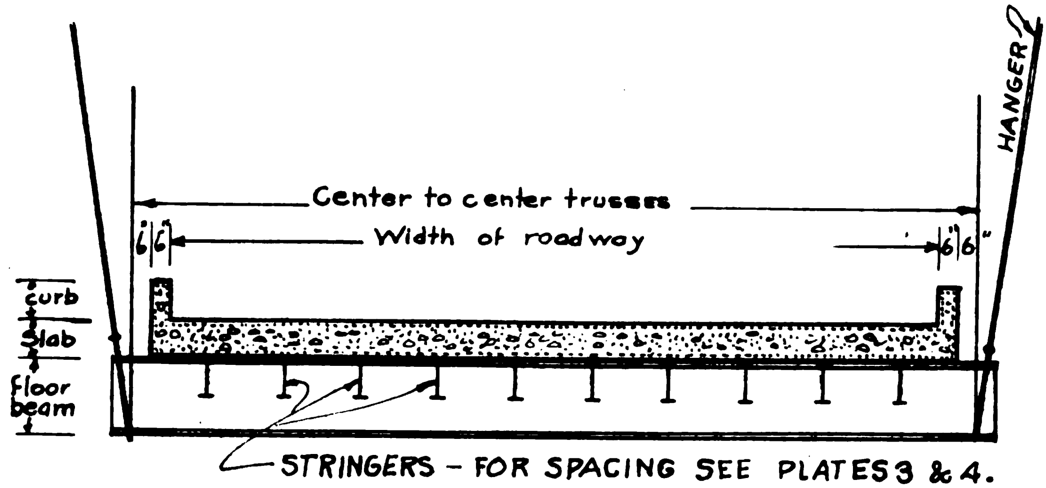


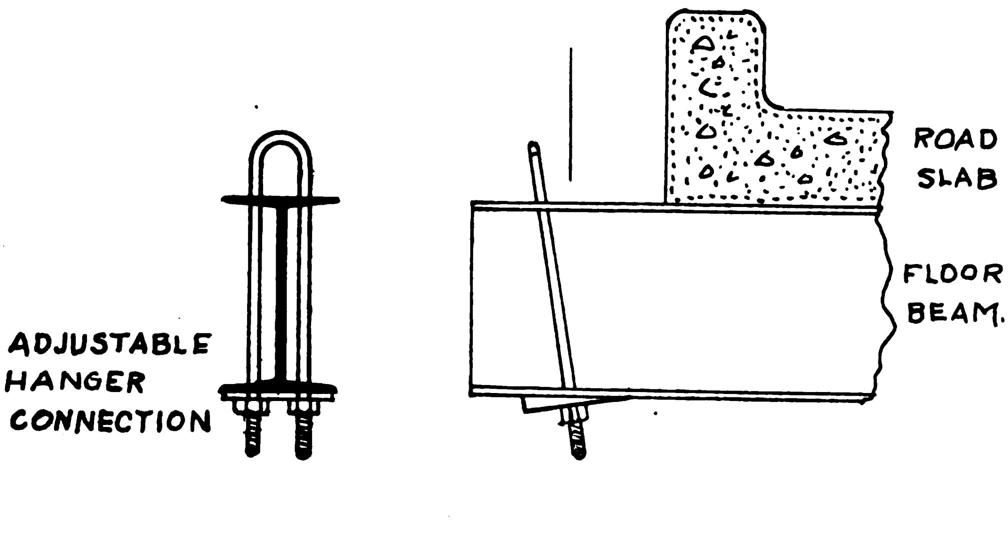
TYPICAL LAYOUT

Plate "A"

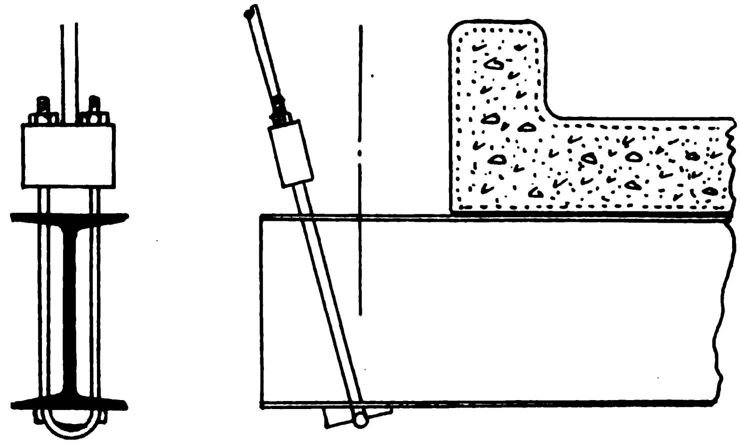


TYPE OF STIFFENING TRUSS

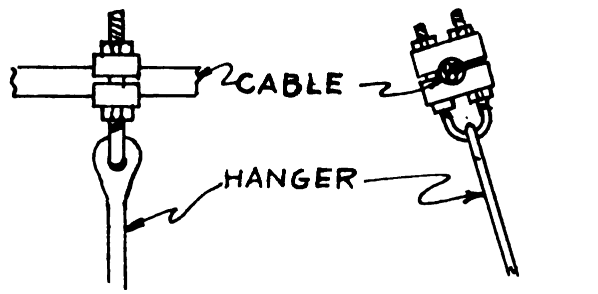




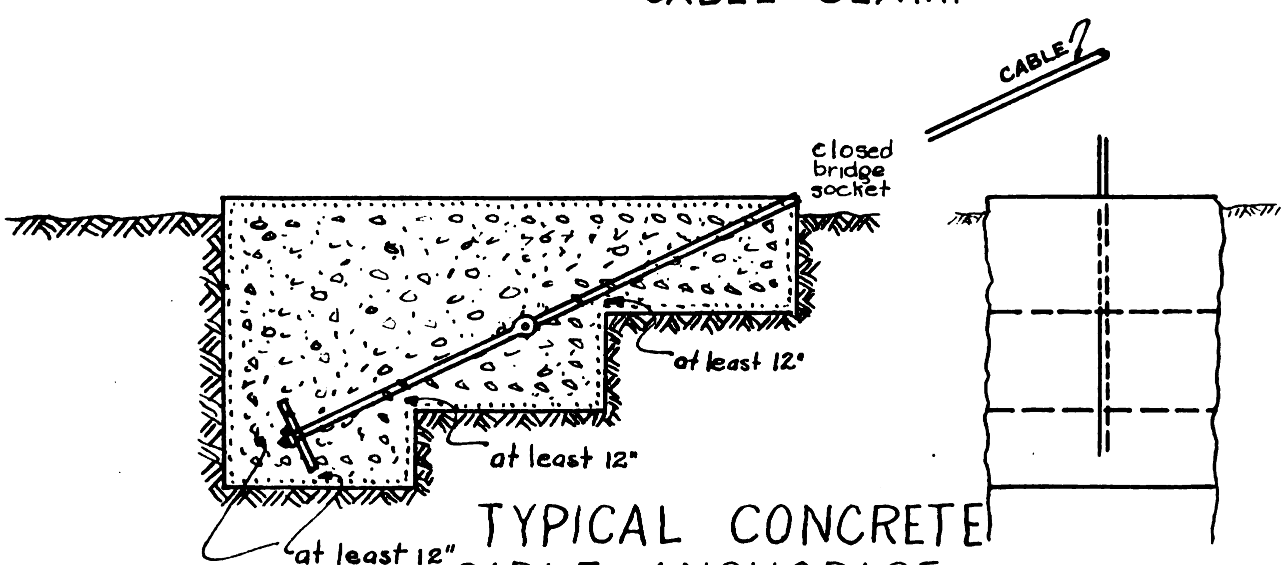
TYPICAL DETAILS
Plate "B"



ADJUSTABLE HANGER CONNECTION



CABLE CLAMP



TYPICAL CONCRETE CABLE ANCHORAGE

DETAILS
Plate "C"

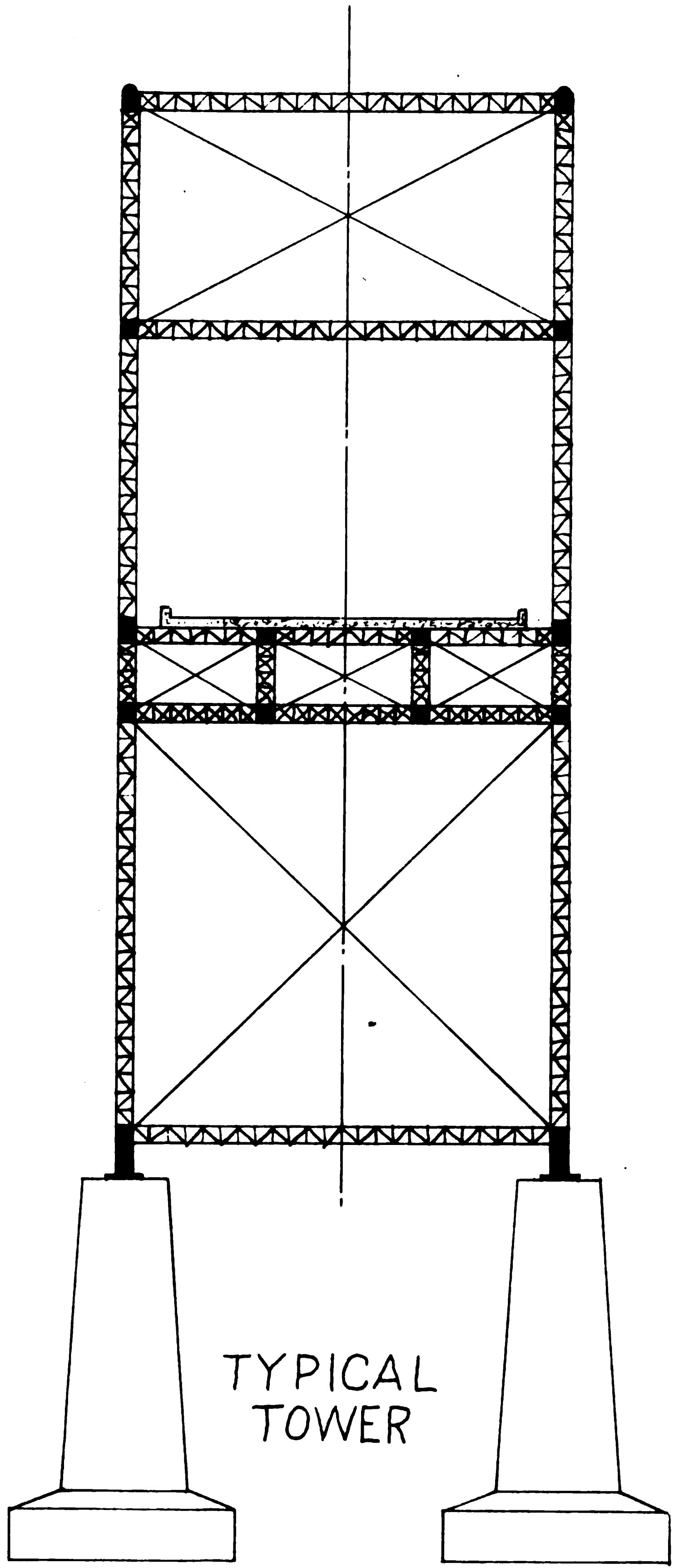
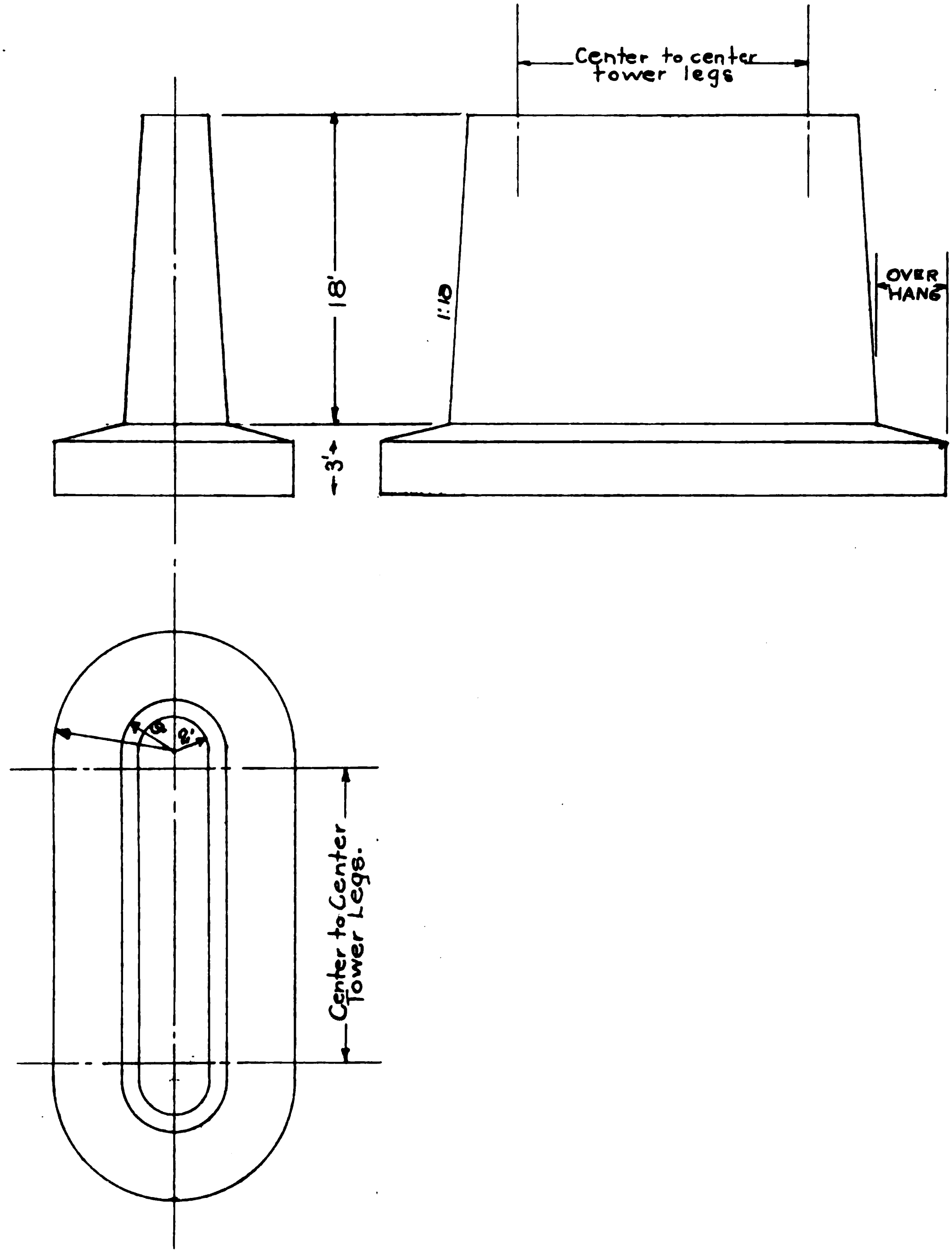


Plate D.

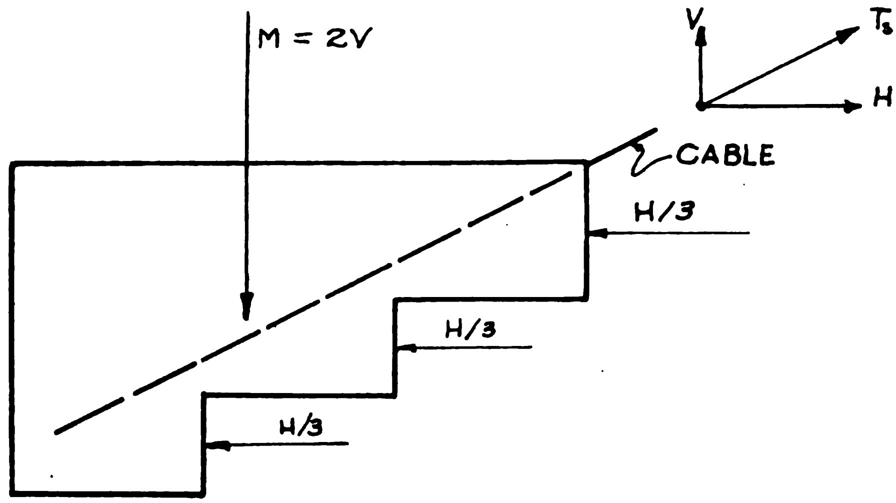


PIER SUPPORTED ON 20 TON PILES.
ONE PILE TO 9 SQUARE FEET.

SEE PLATE 16

TYPICAL PIER

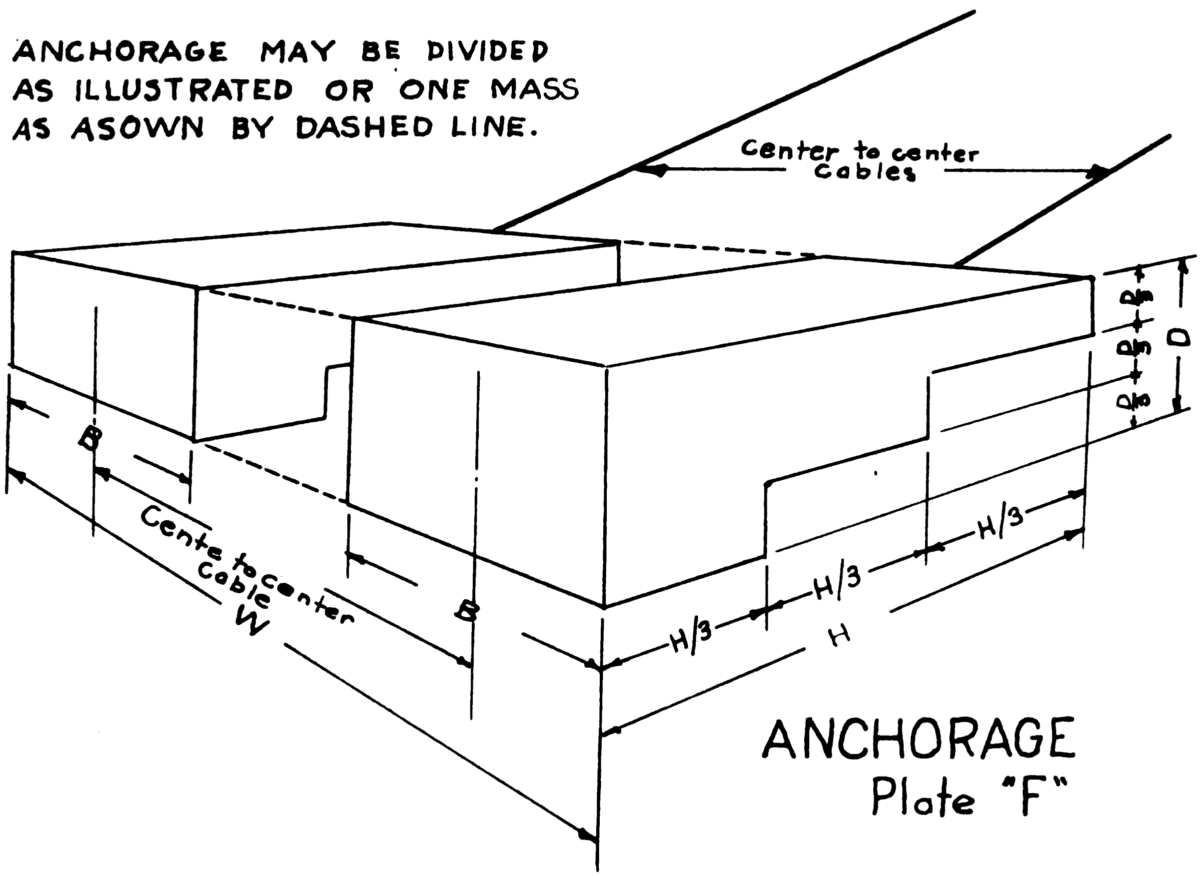
Plate "E"



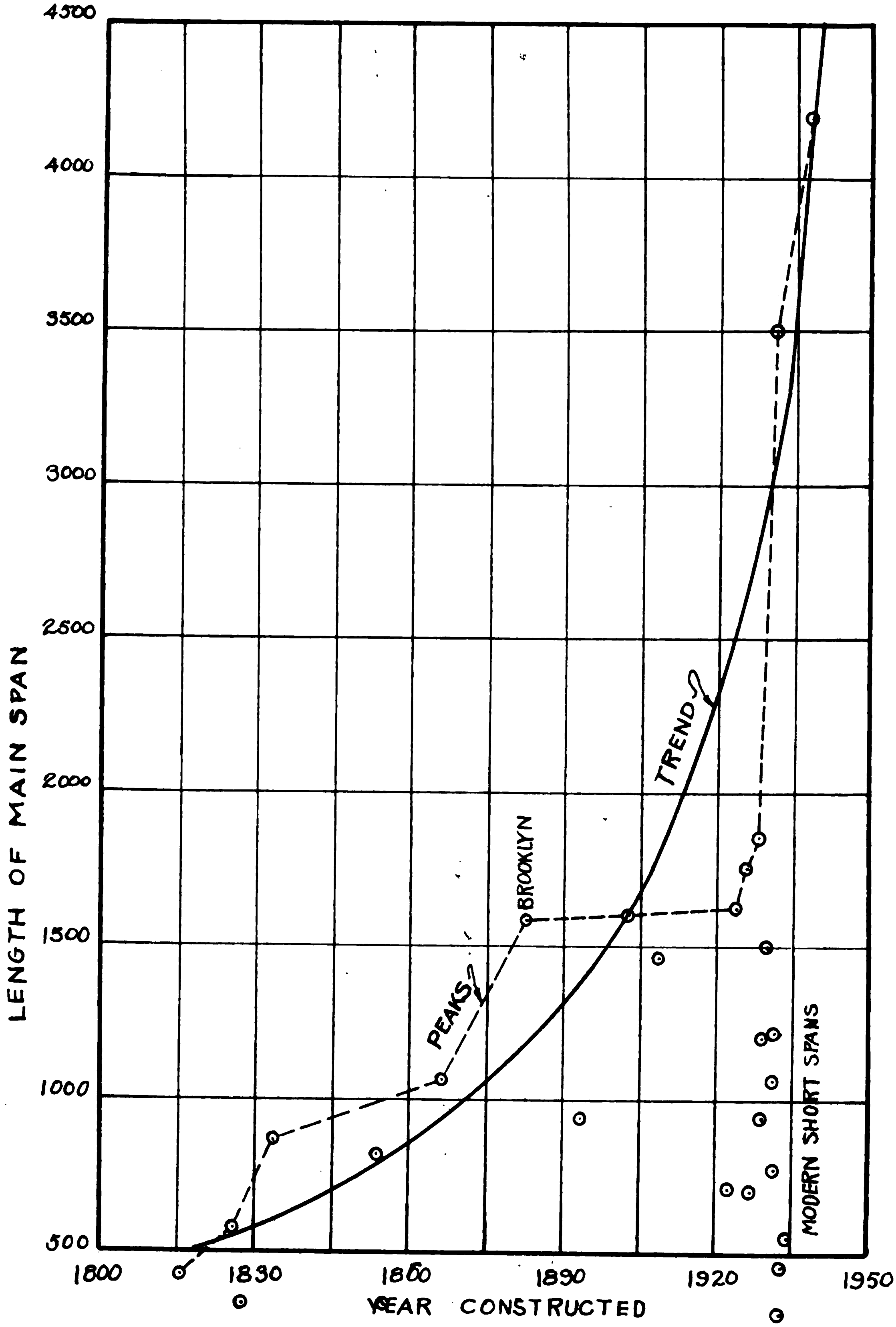
HORIZONTAL COMPONENT OF ACTUAL CABLE TENSION RESISTED BY EARTH BEARING PRESSURE ON FRONT SURFACE OF ANCHORAGE – EARTH PRESSURE VALUE TAKEN AT 2000 POUNDS PER SQUARE FOOT.

TOTAL WEIGHT OF ANCHORAGE EQUAL TWICE THE VERTICAL COMPONENT OF CABLE TENSION.

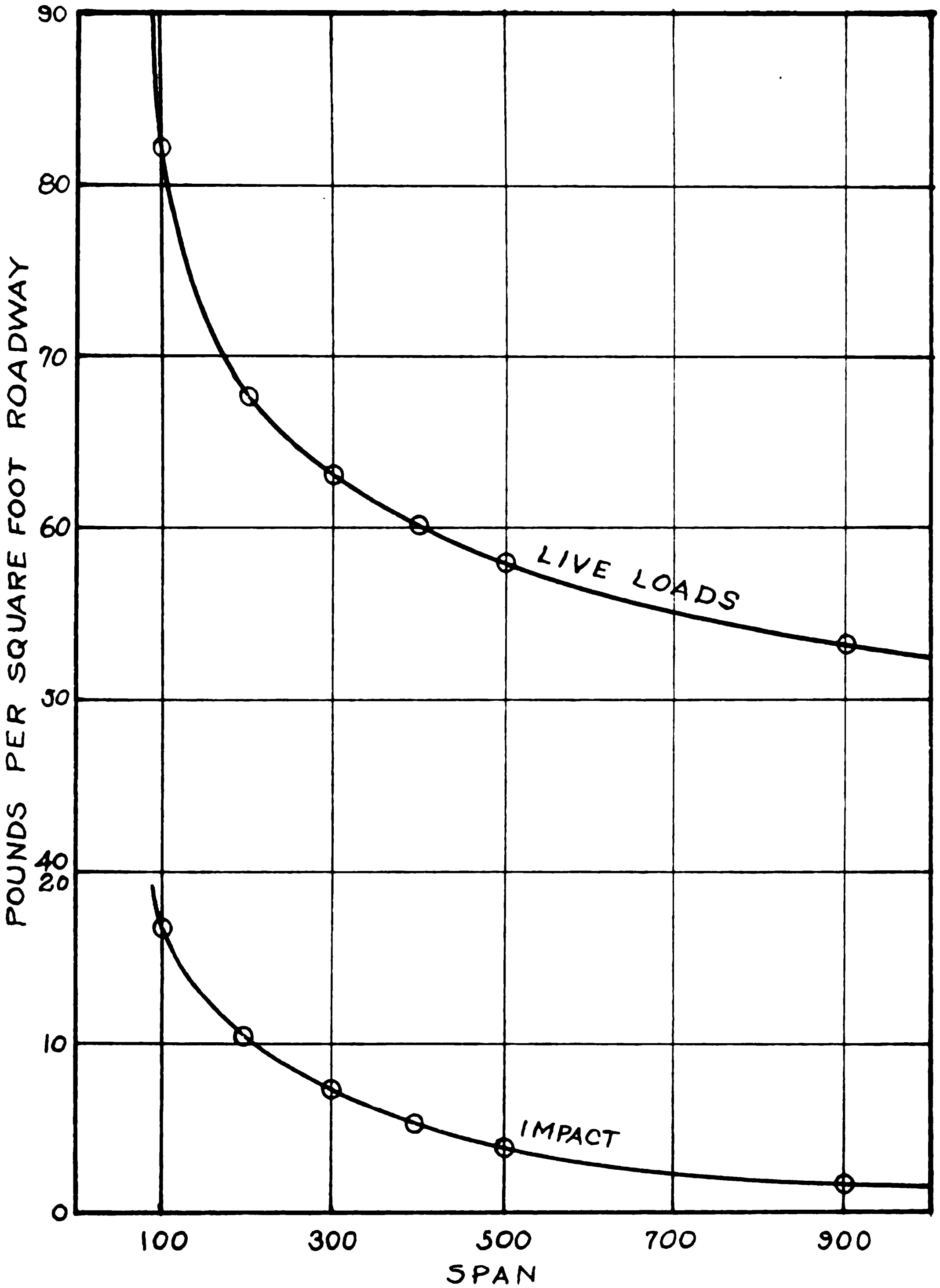
ANCHORAGE MAY BE DIVIDED AS ILLUSTRATED OR ONE MASS AS ASOWN BY DASHED LINE.



ANCHORAGE
Plate "F"



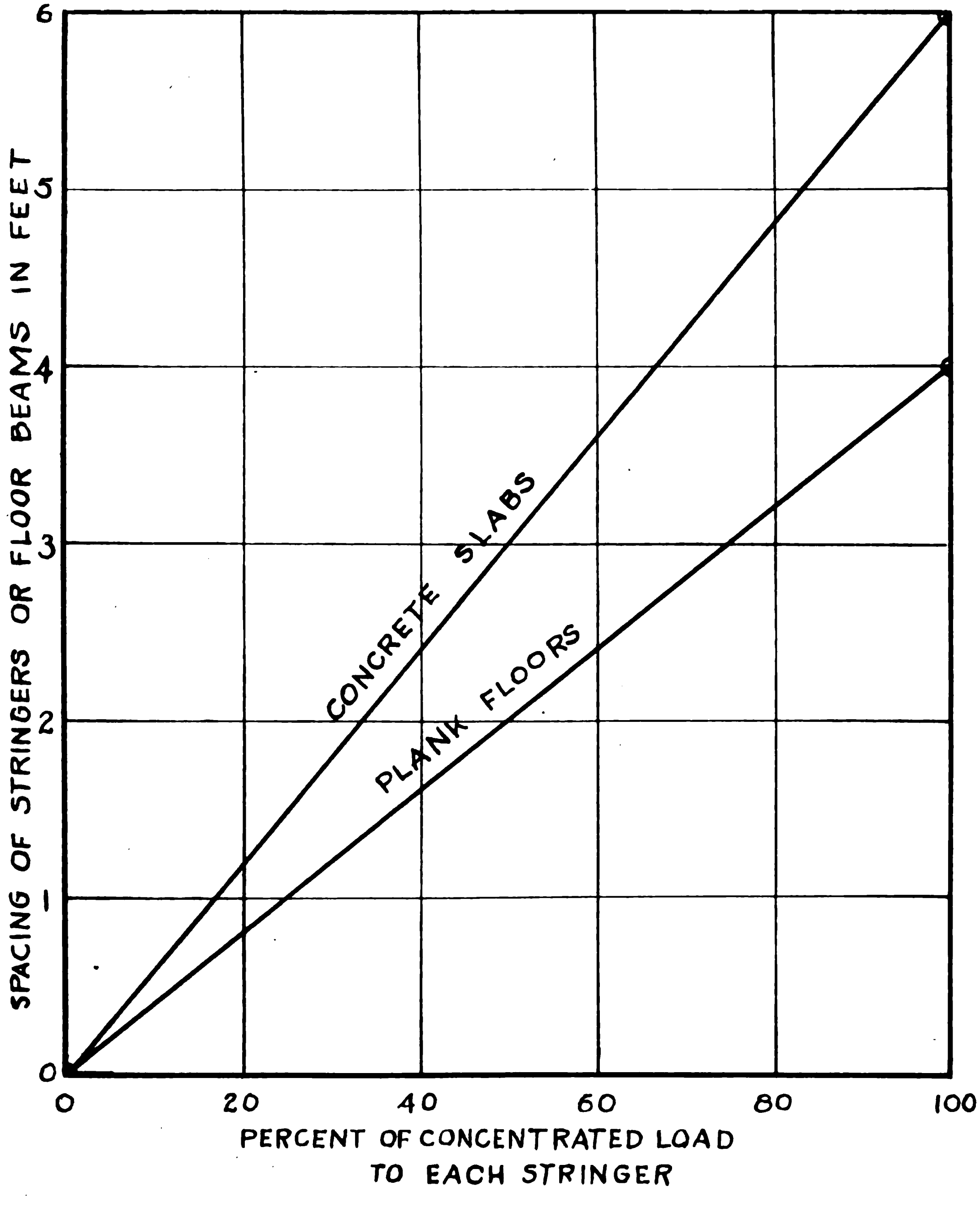
SUSPENSION BRIDGES
Plate 1.



H-15 LOADING

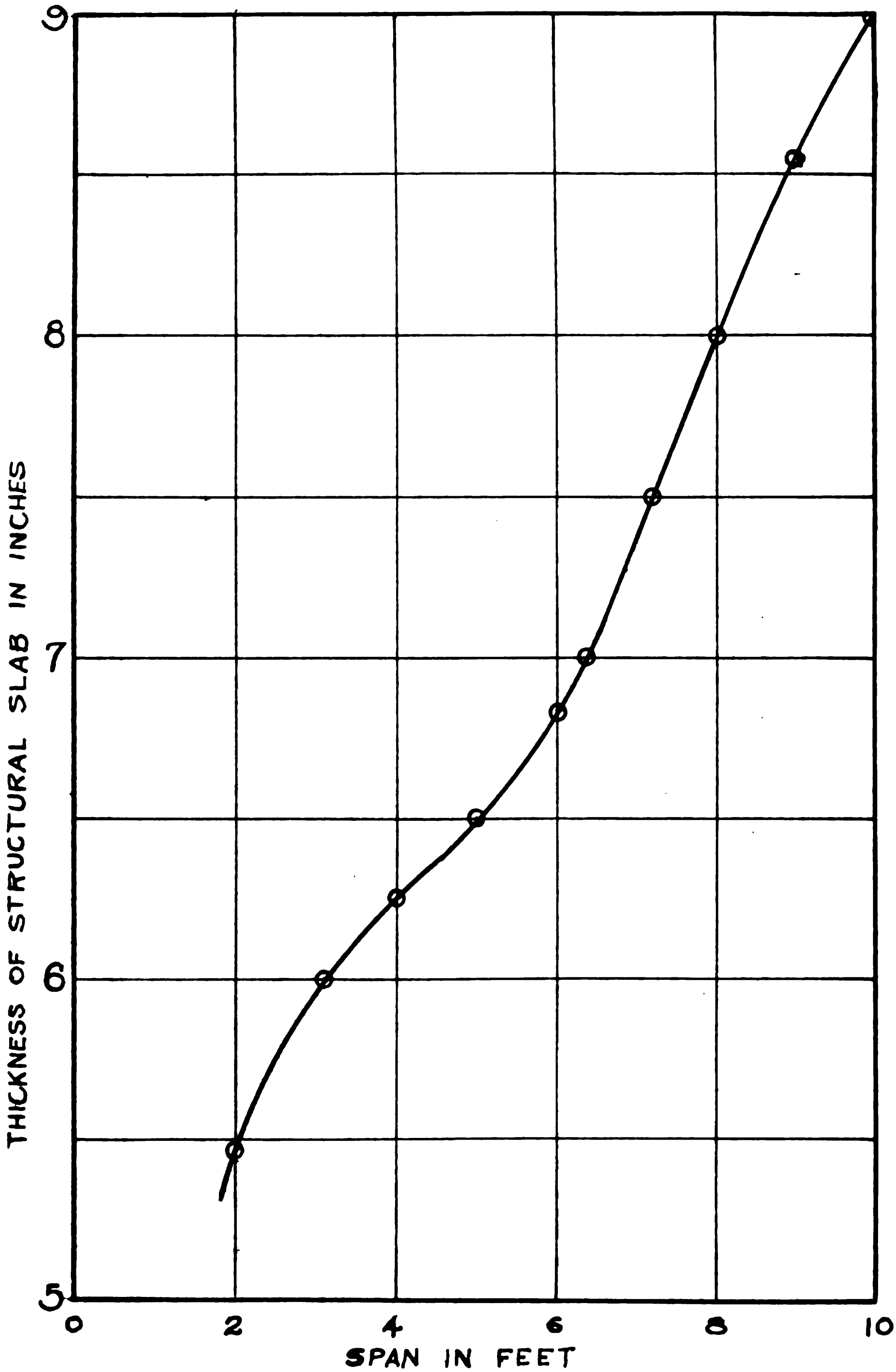
LIVE LOADS AND IMPACT

Plate 2.



LOADS TO STRINGERS OR FLOOR BEAMS

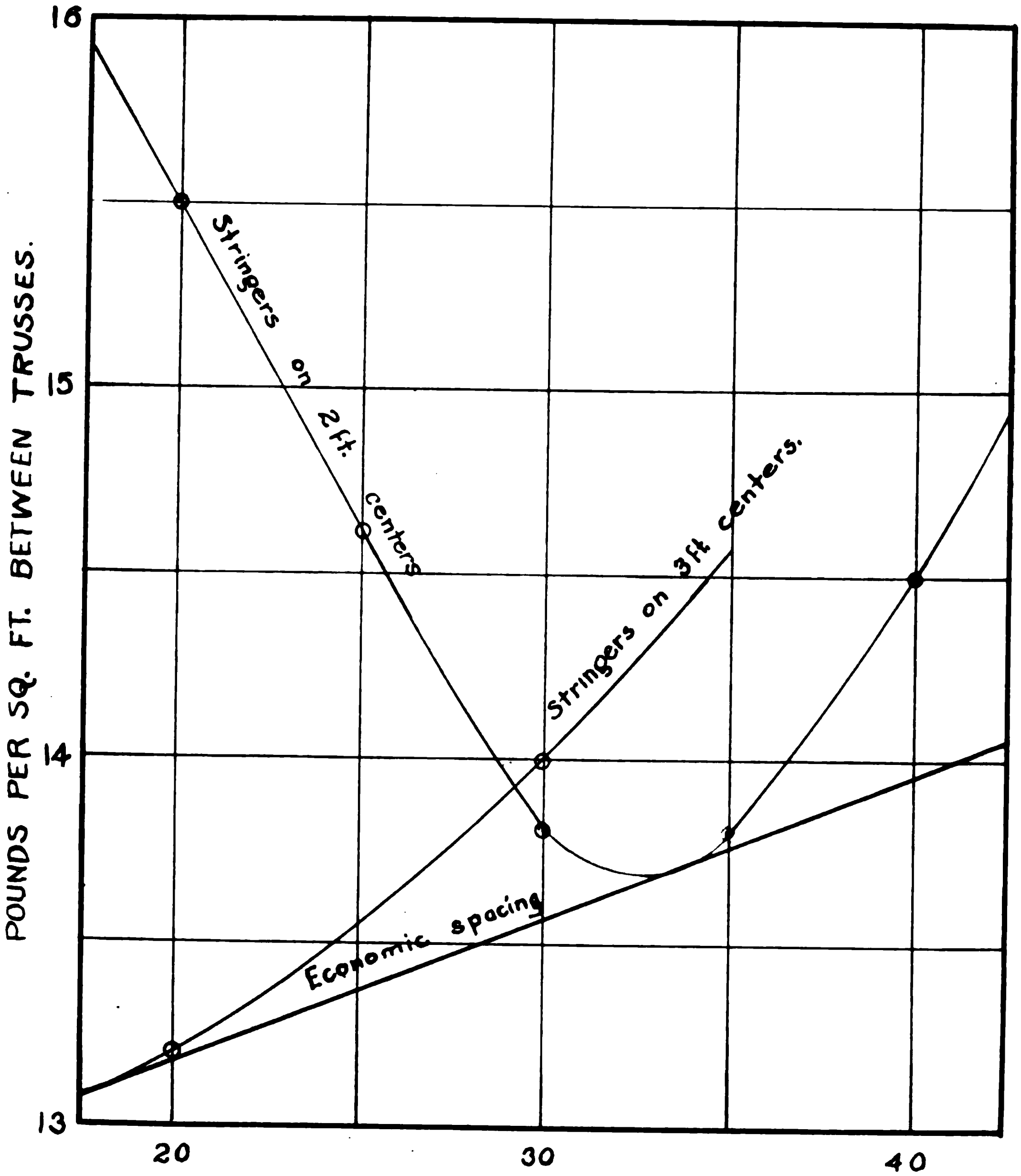
Plate 3.

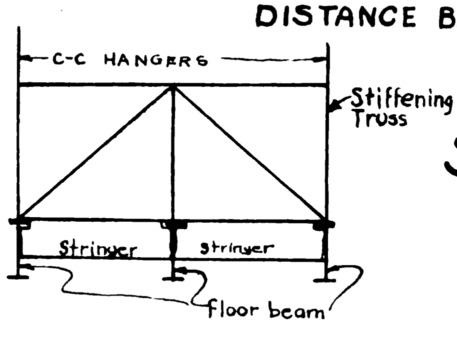


H-15 LOADING

CONCRETE SLAB ON STEEL JOISTS

Plate 4.

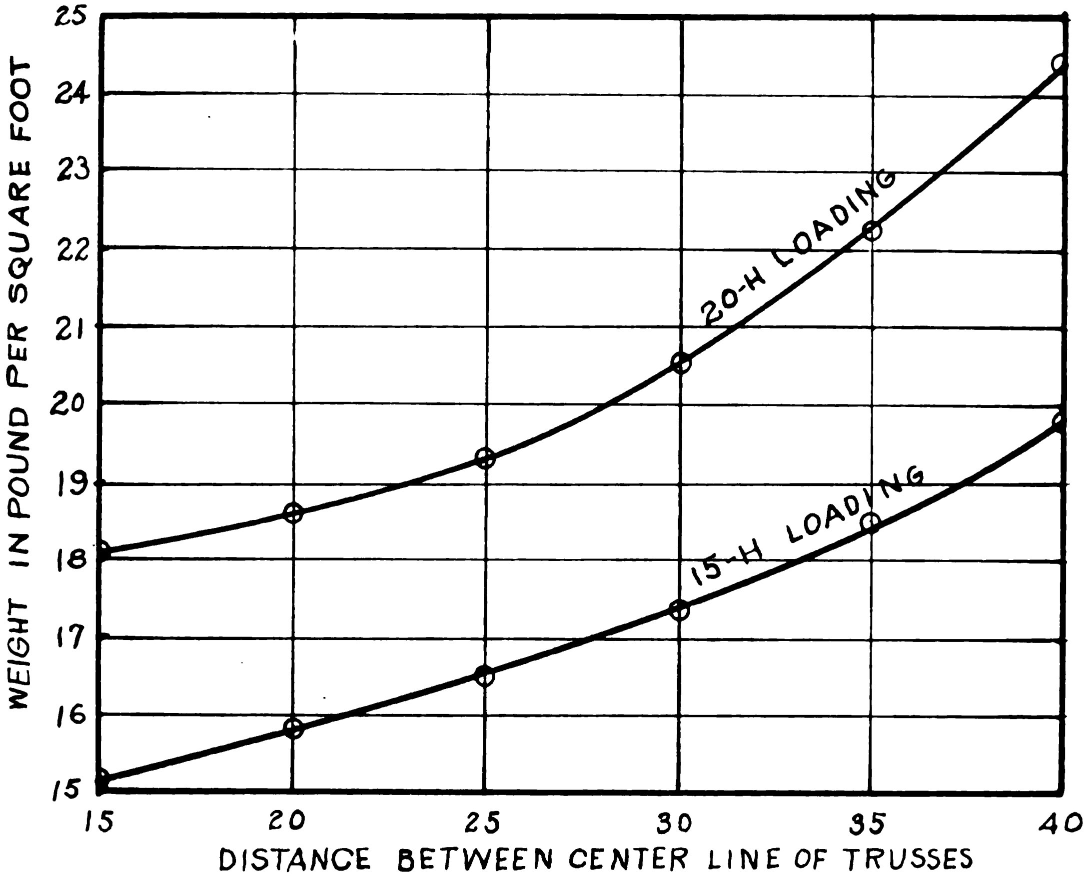




H-15 Loading, 22 ft truss to truss.

STEEL IN FLOOR SYSTEM

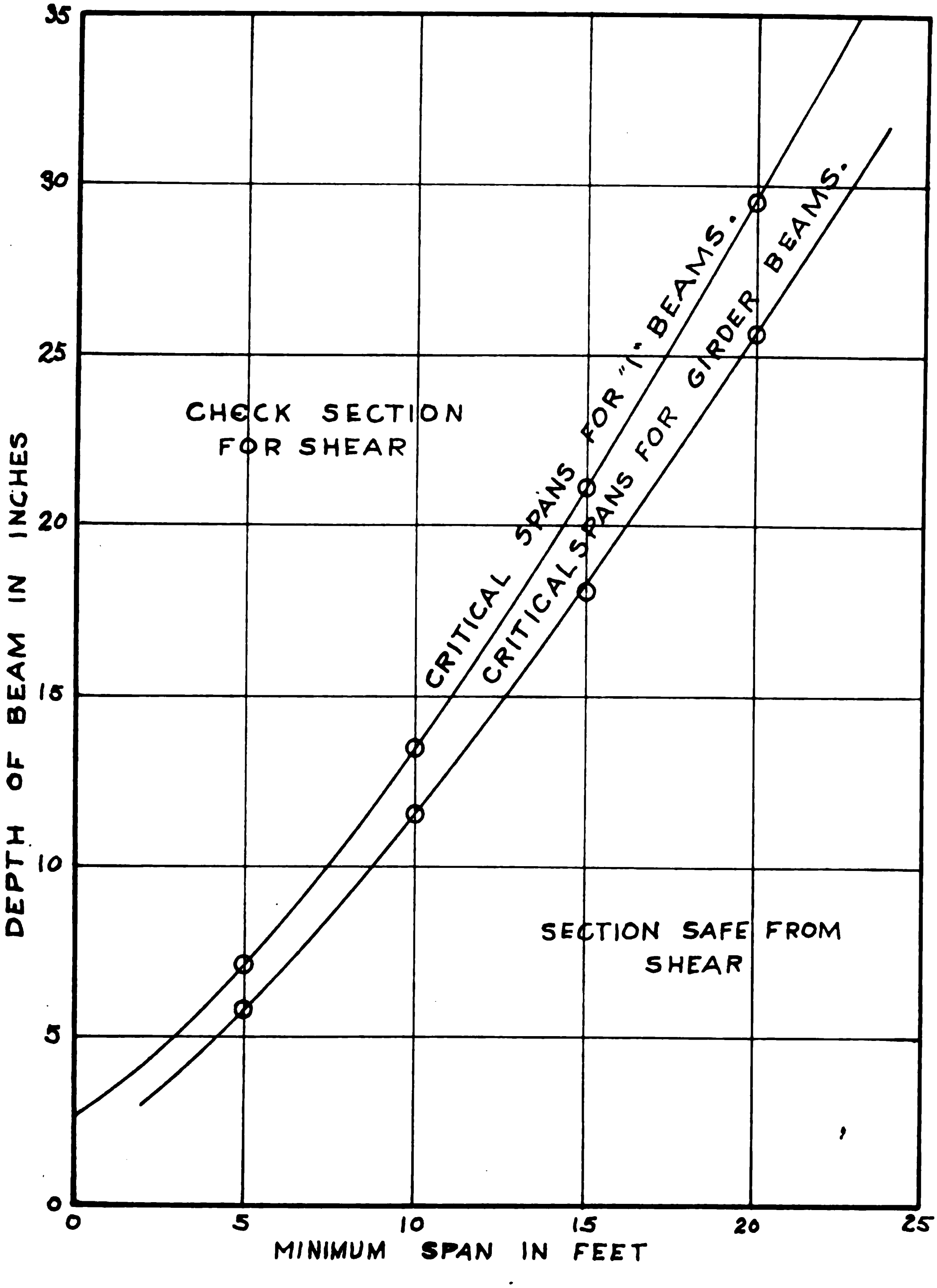
Plate 5.



LATERAL AND SWAY BRACING INCLUDED.

STEEL IN FLOOR SYSTEM.

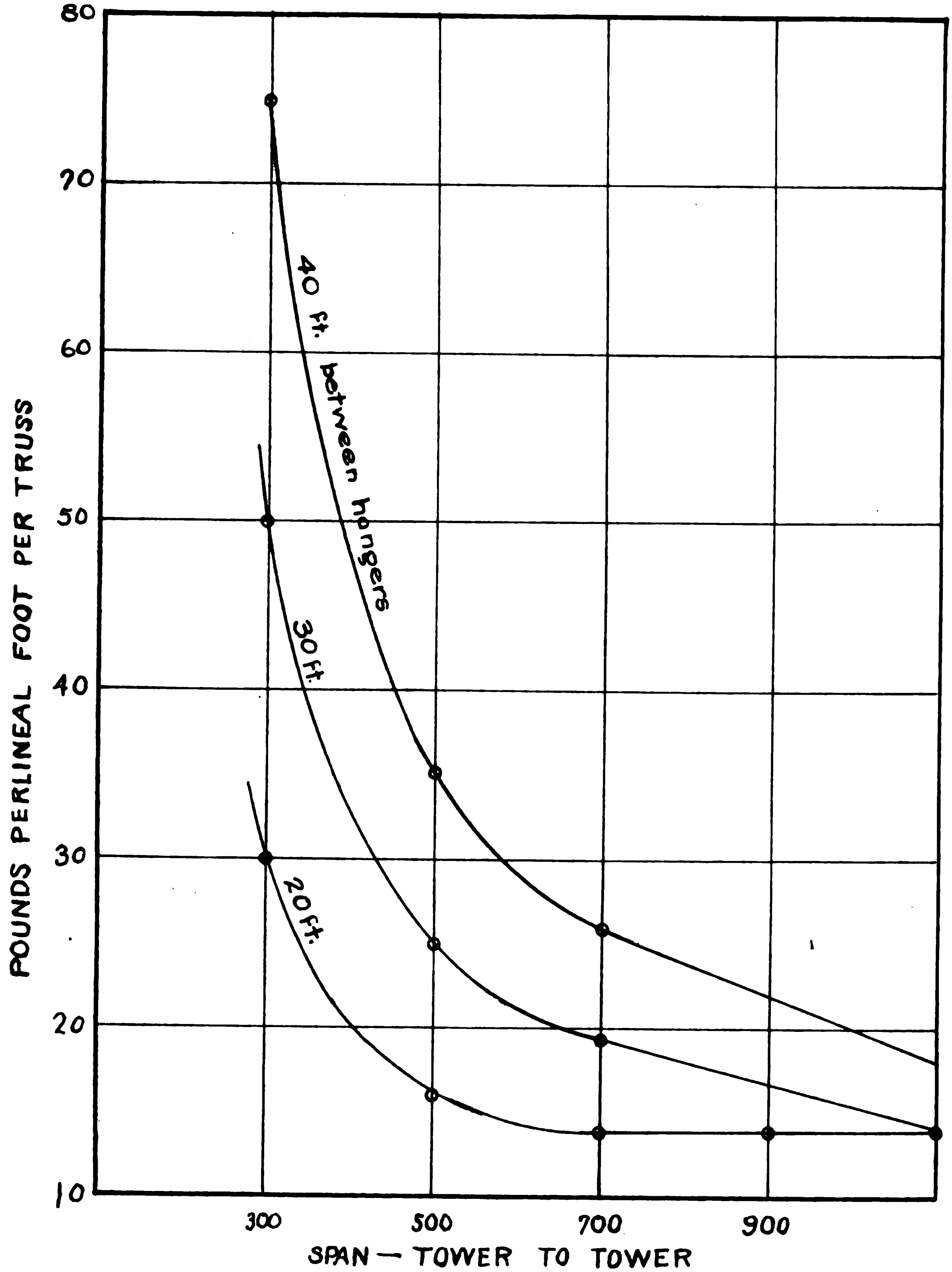
Plate 5A.



I AND GIRDER BEAMS

LIMITING SPANS

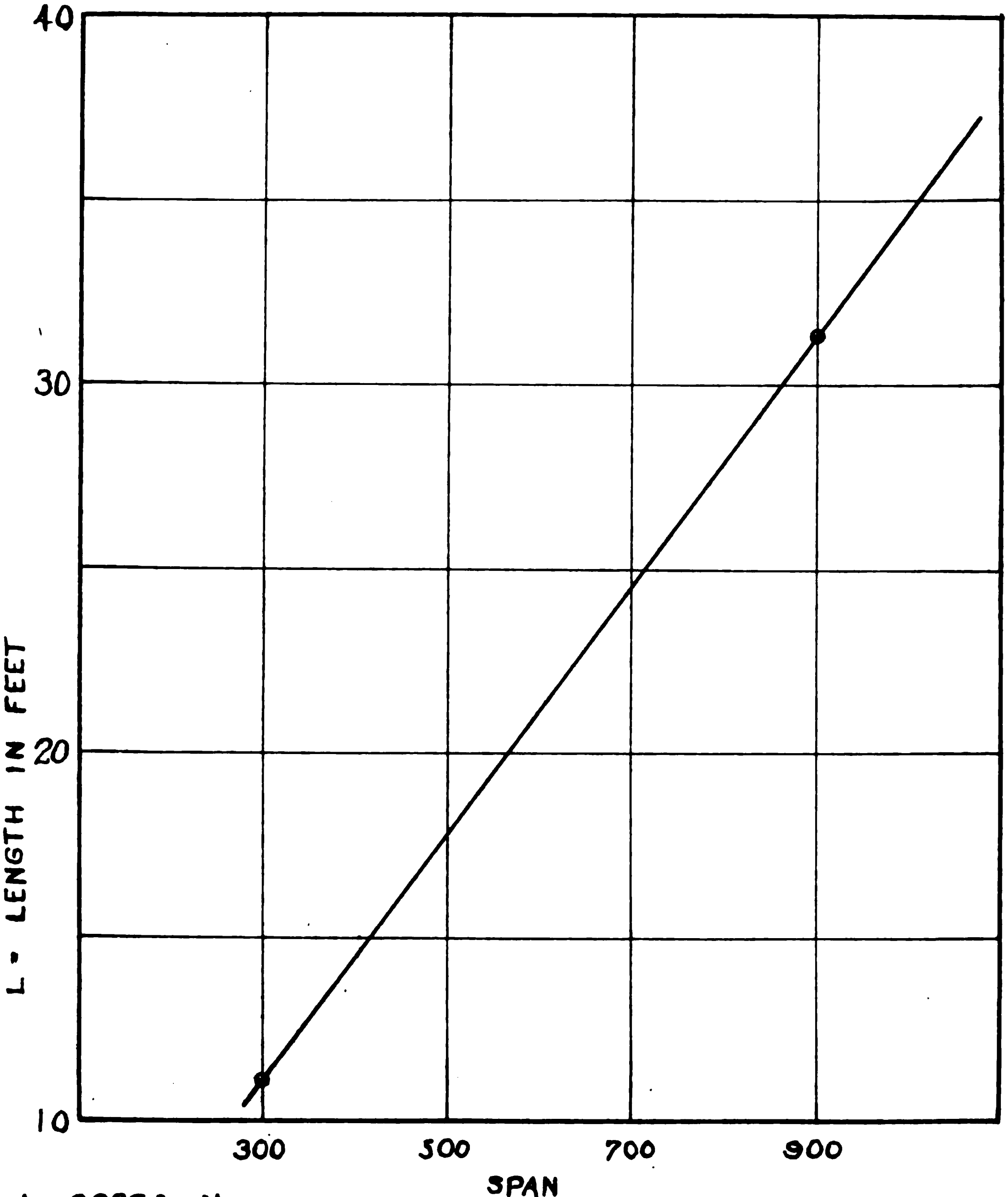
Plate 6.



H-15 loading, 22 ft truss to truss.

METAL IN STIFFENING TRUSS

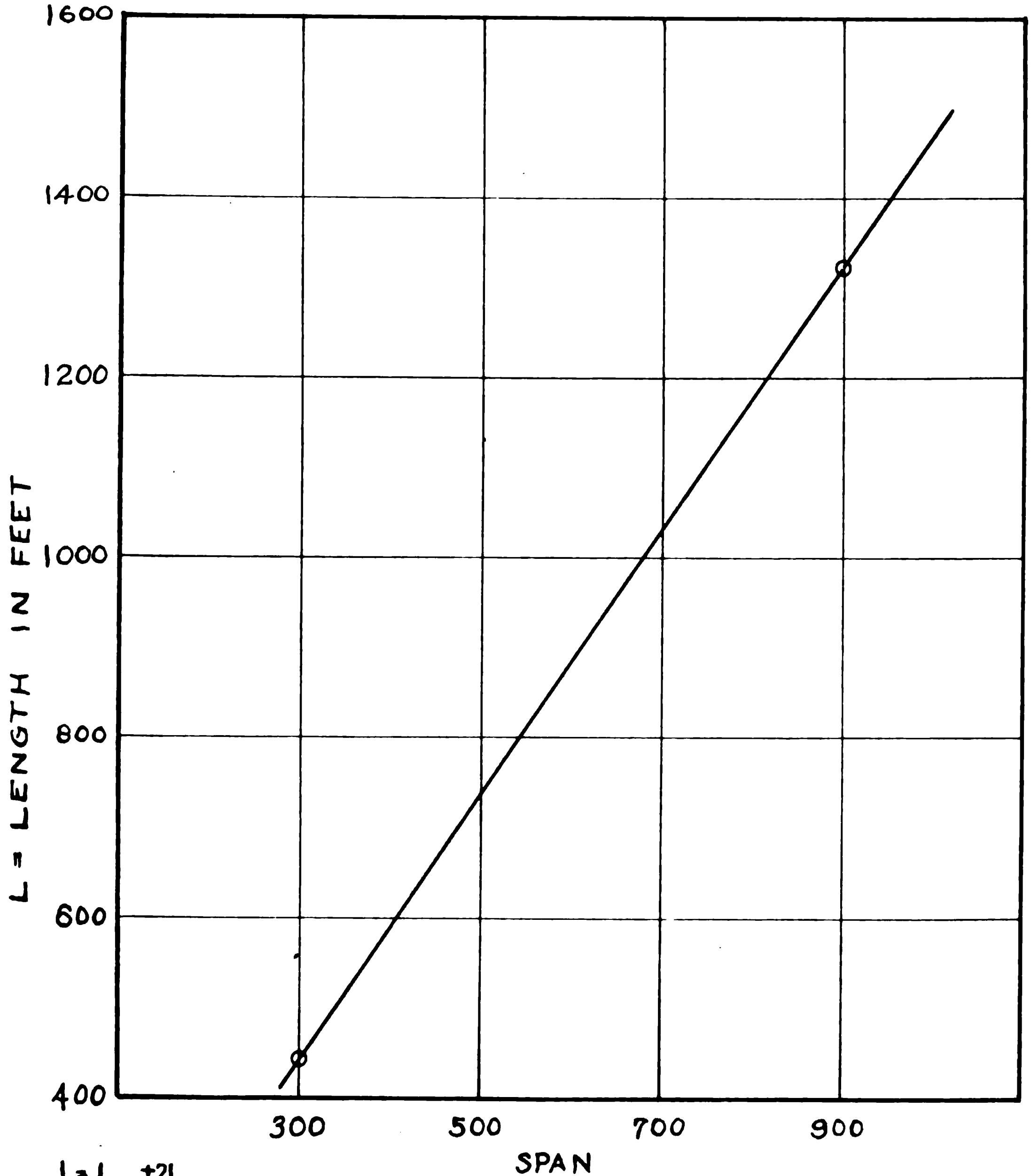
Plate 7.



L=.0337 l + N
when lo=l/d
N= Min. length = 1'0"

AVERAGE LENGTH OF HANGERS

Plate 8.



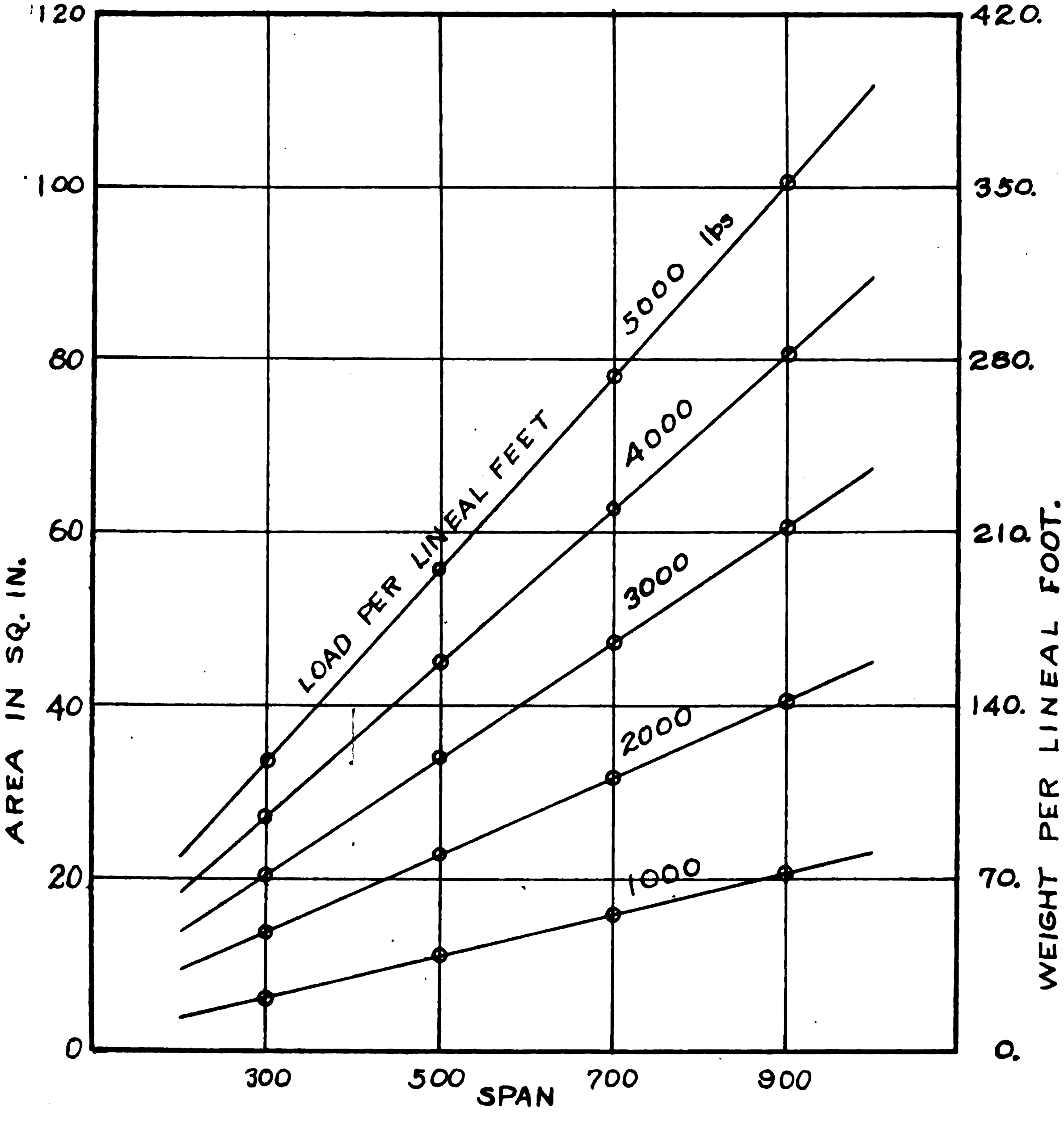
$L = L_M + 2L_s$

$L_M = l + \frac{8d^2}{3l}$

$L_s = (d^2 + \overline{2d}^2)^{\frac{1}{2}}$

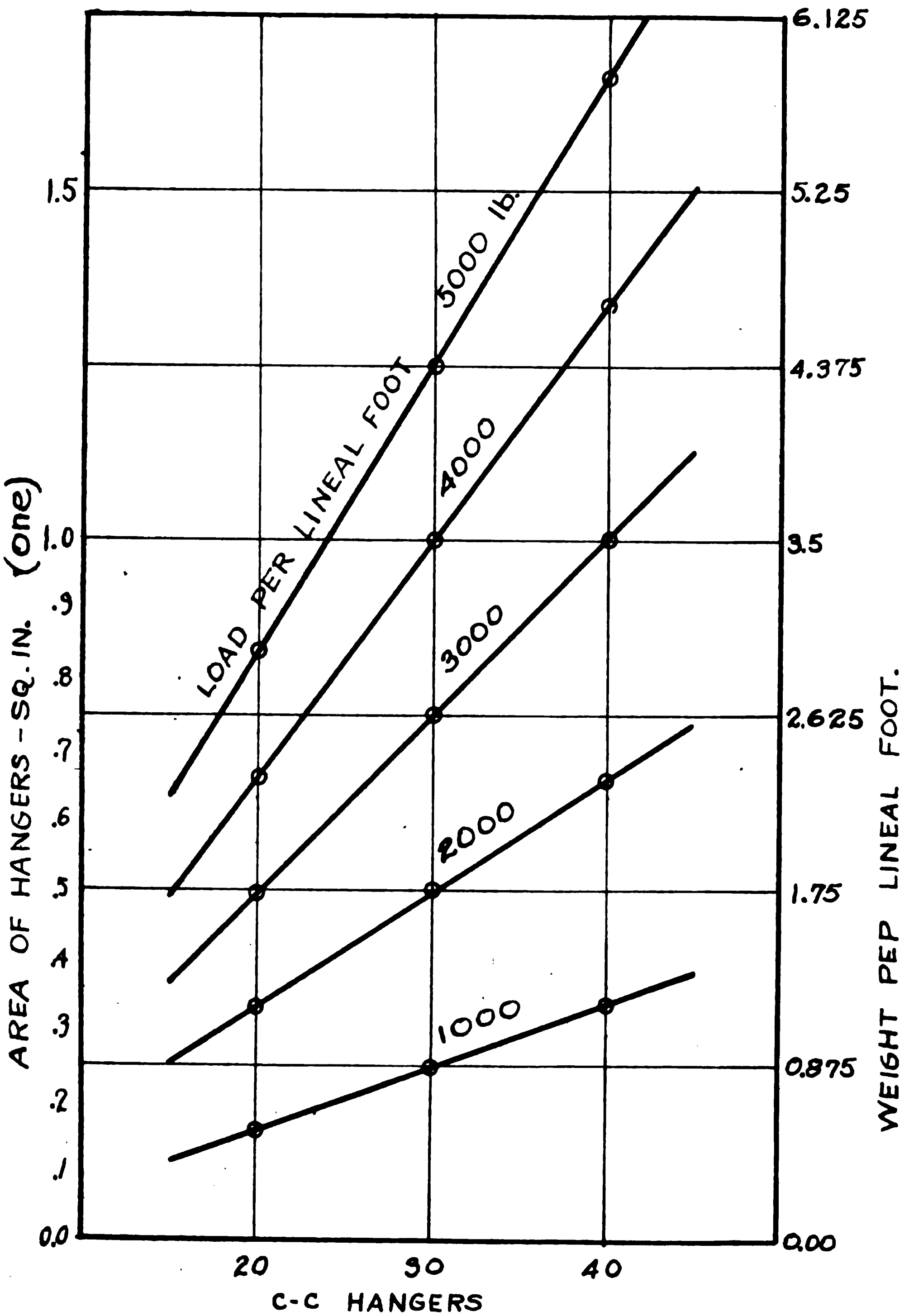
LENGTH OF MAIN CABLES

Plate 9.



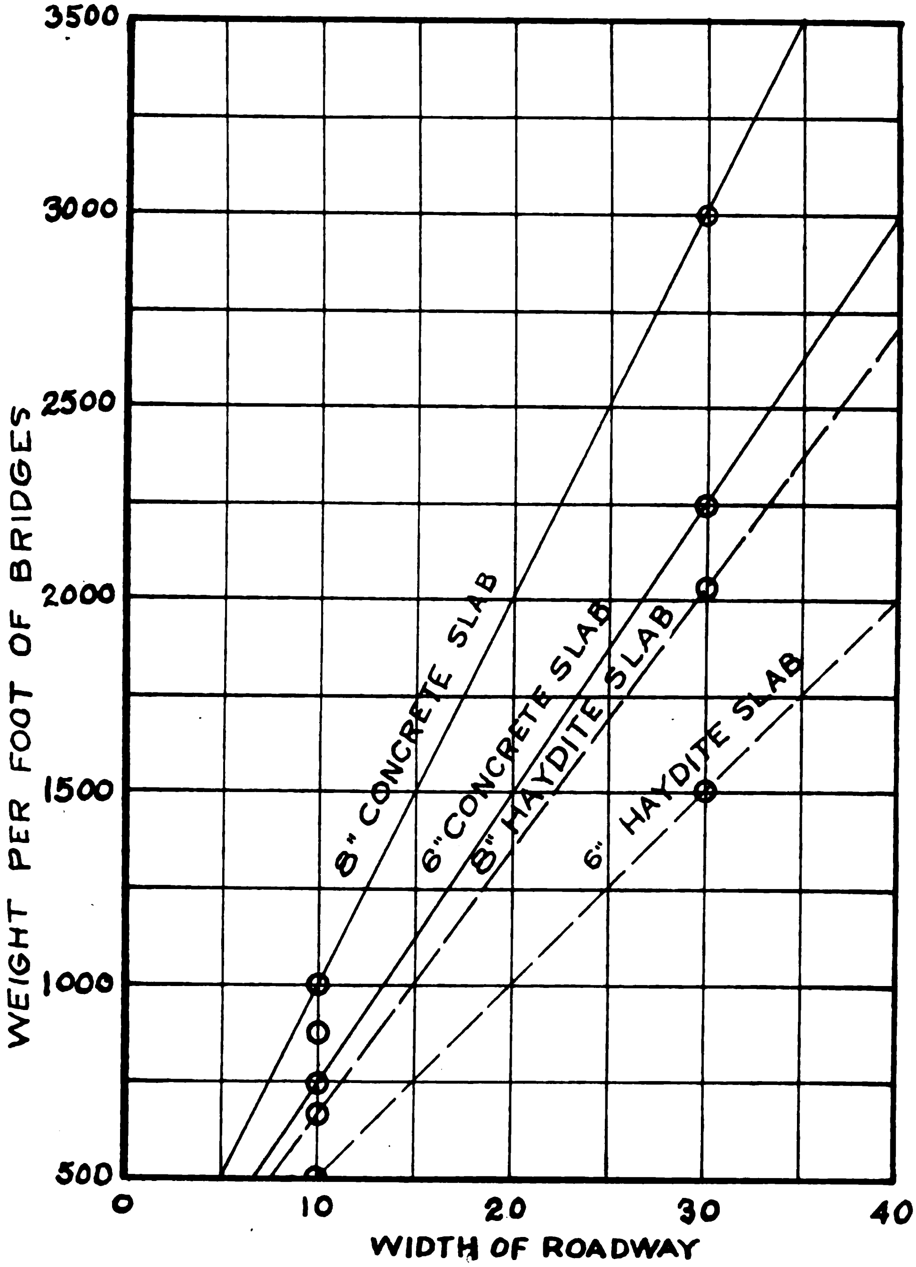
AREA OF MAIN CABLE

Plate 10.



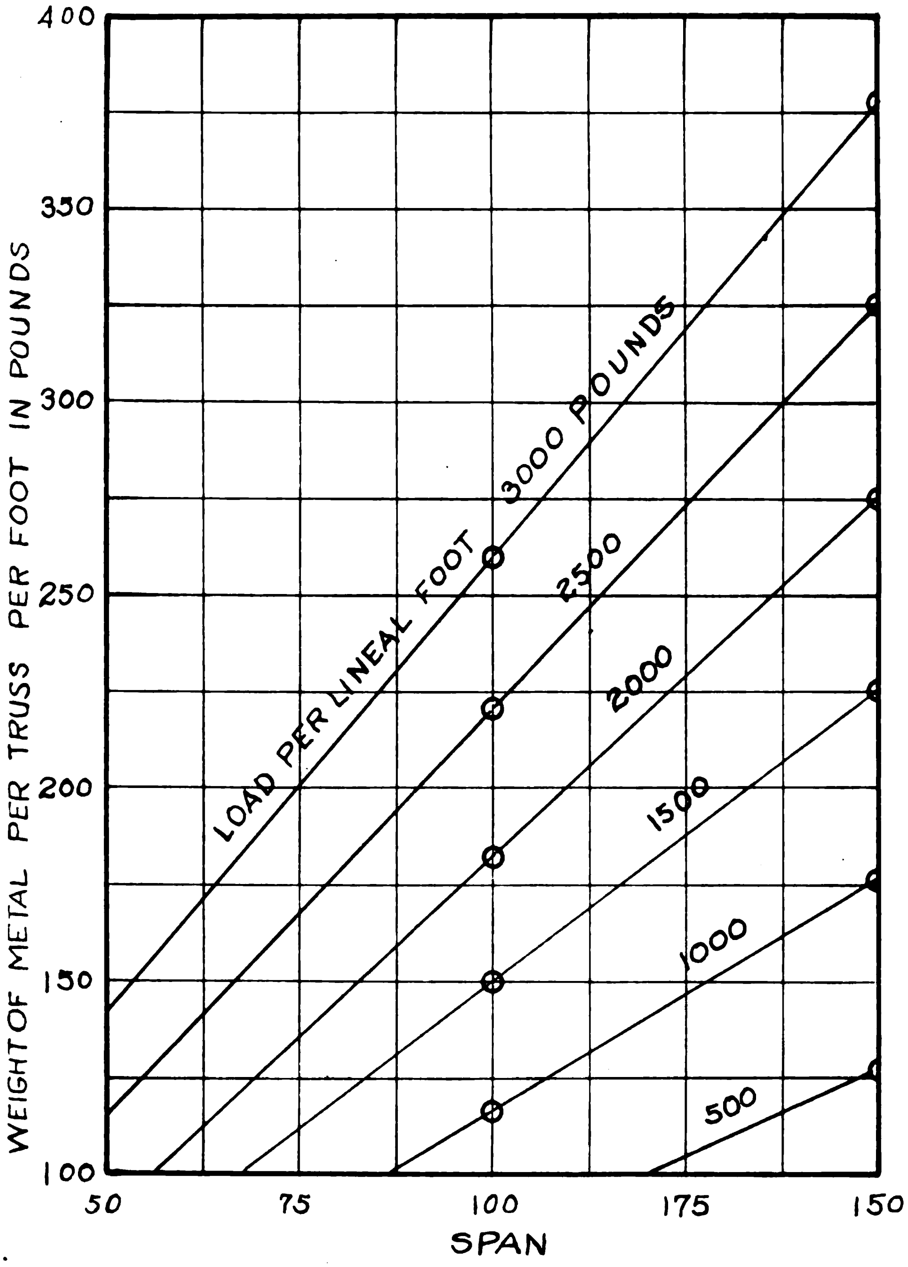
AREA OF HANGER

Plate 11.



CONCRETE BRIDGE FLOORS

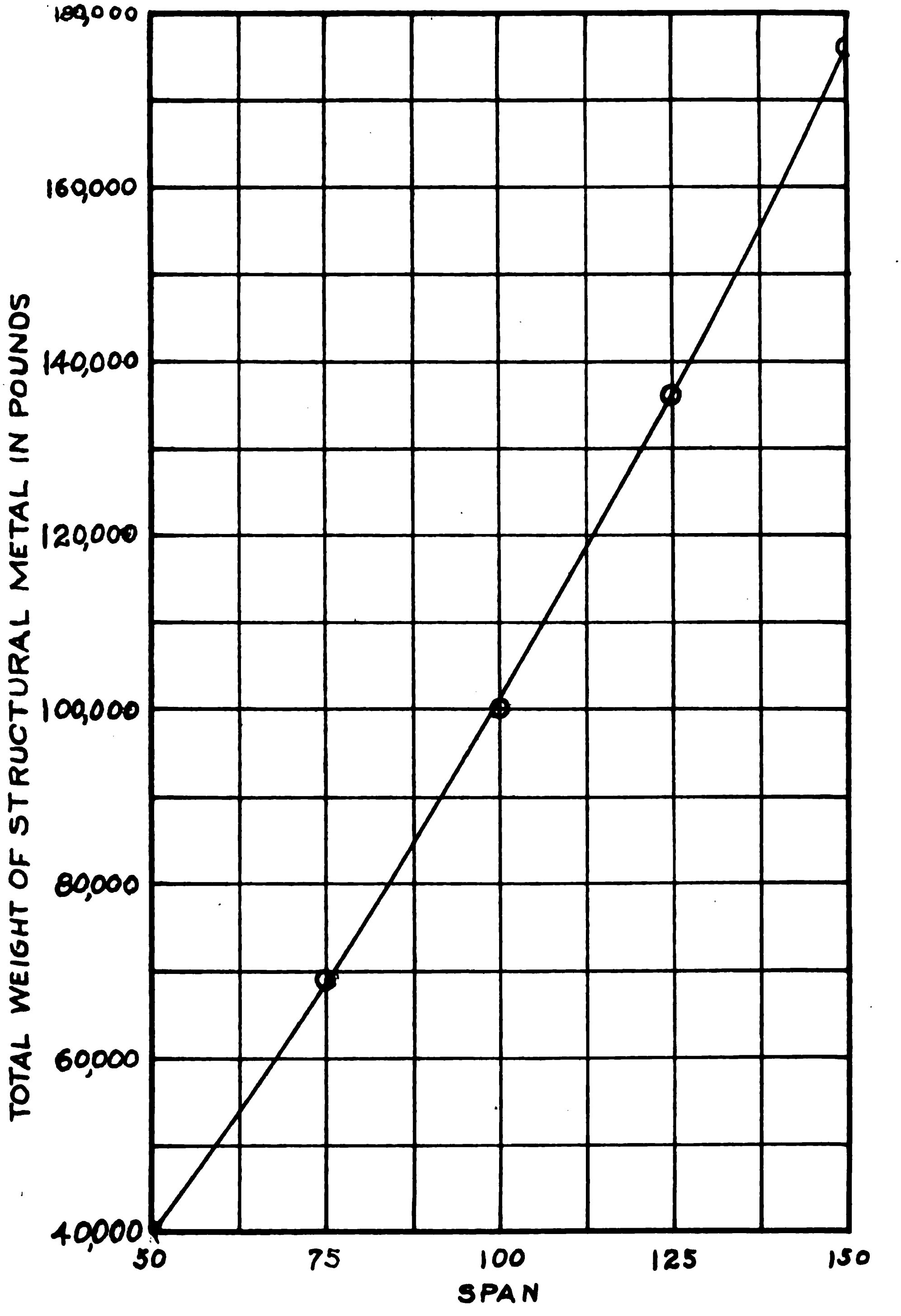
Plate 12.



H-15 LOADING

METAL IN TRUSS

Plate 13.

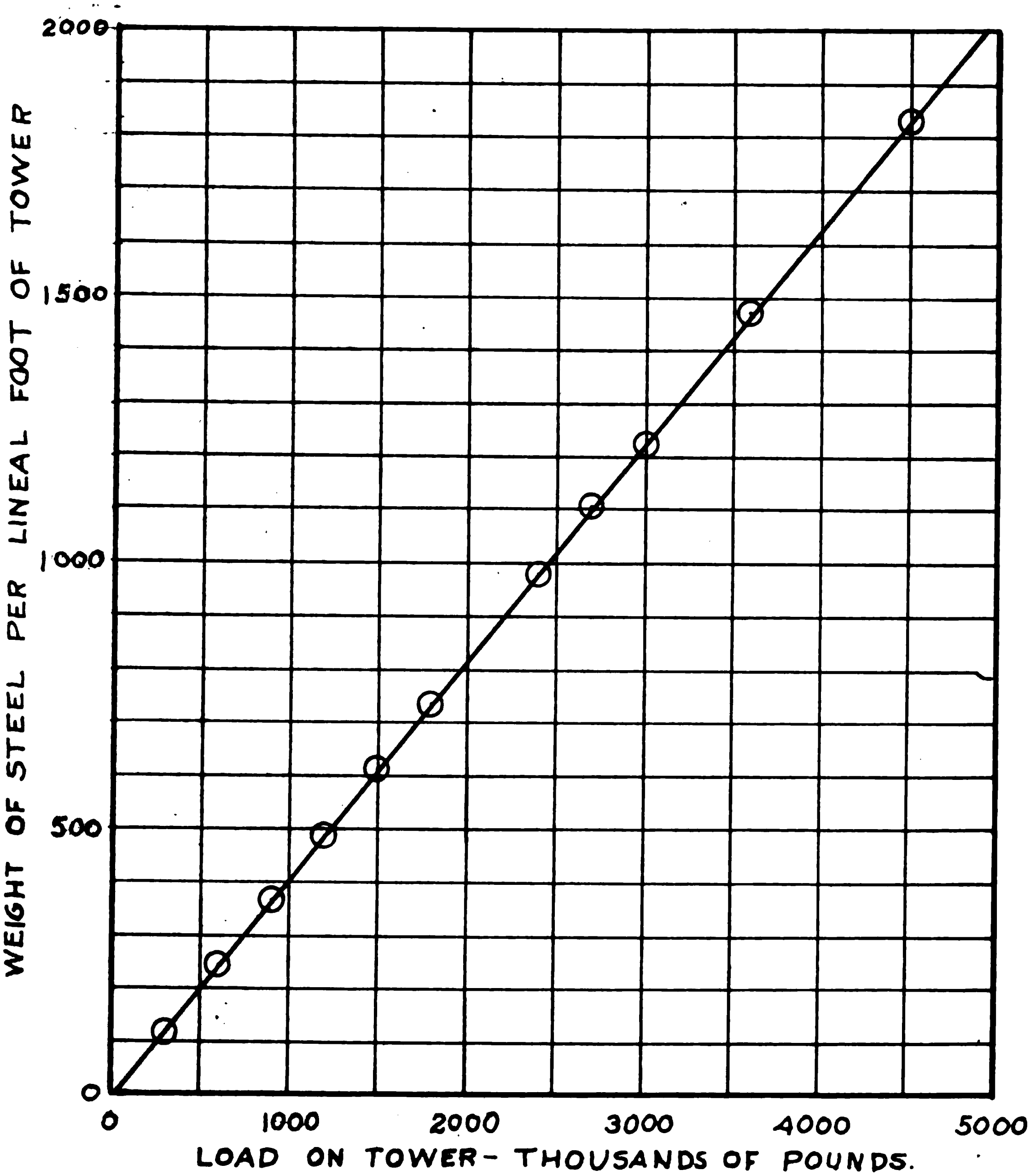


H-15 LOADING, 20 FOOT ROADWAY, 6 INCH SLAB.

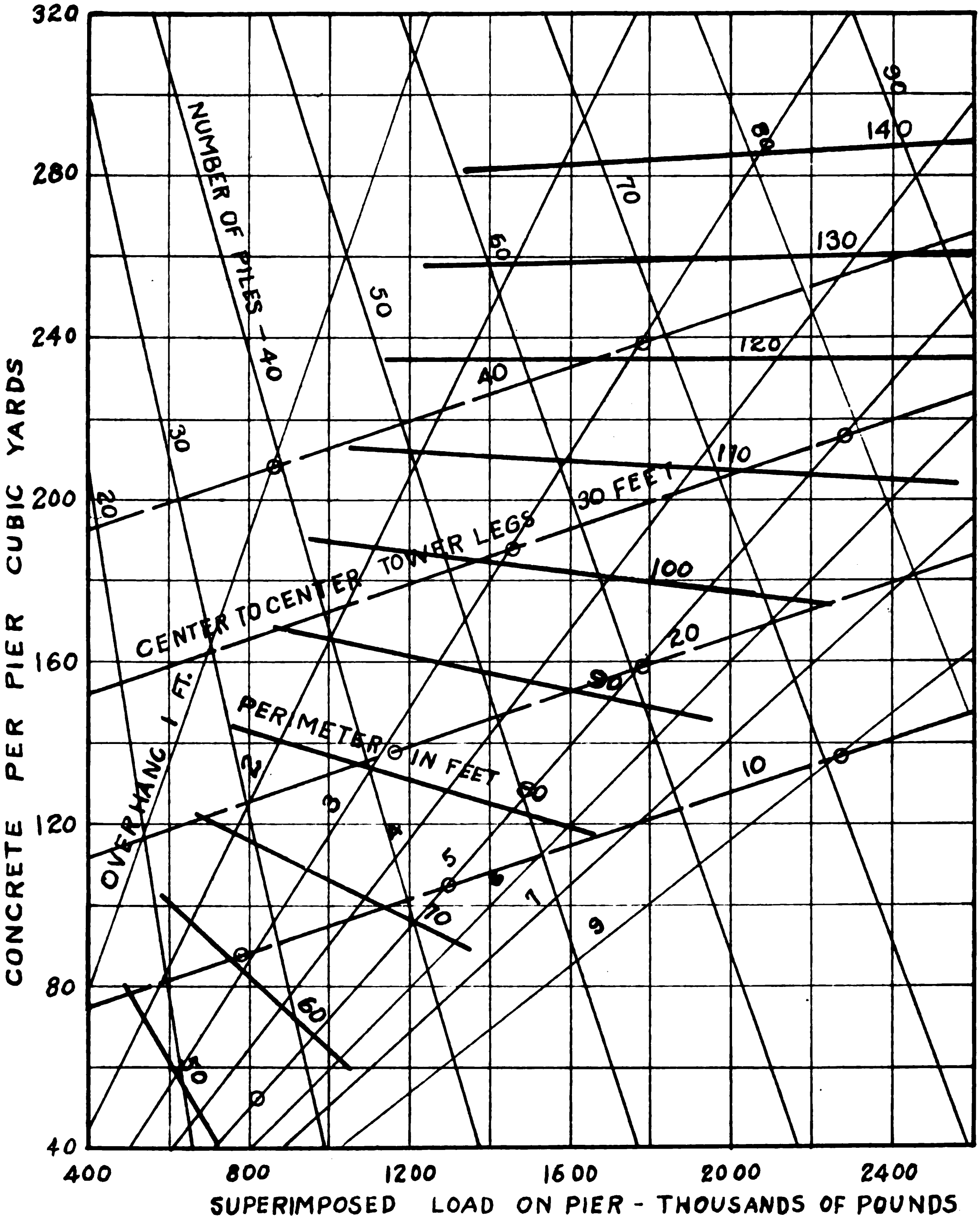
STRUCTURAL METAL IN BRIDGES

DESIGNED IN ACCORD WITH
BUREAU OF PUBLIC ROADS
15 TON LOADING.

Plate 14.

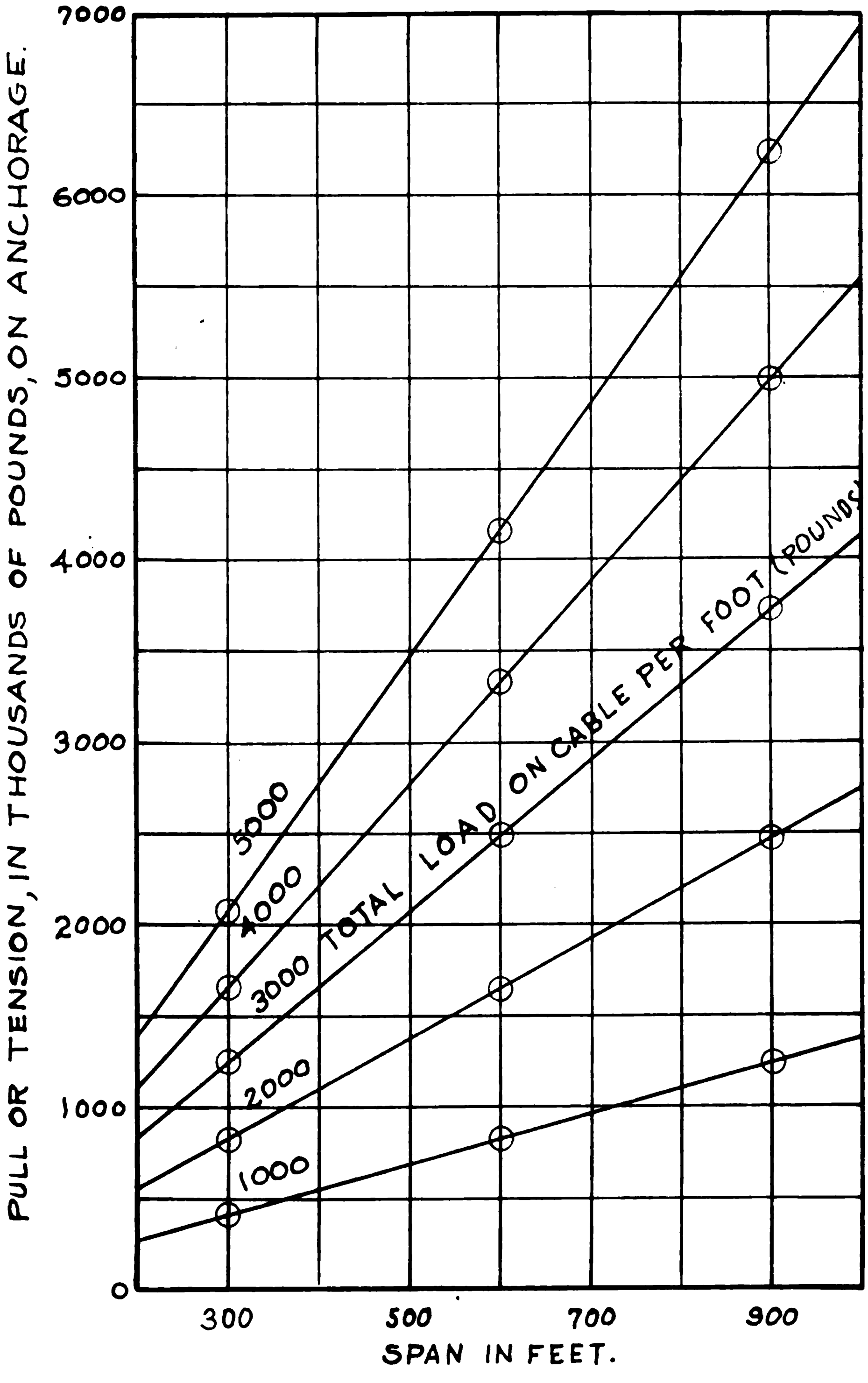


TOWER STEEL
Plate 15.



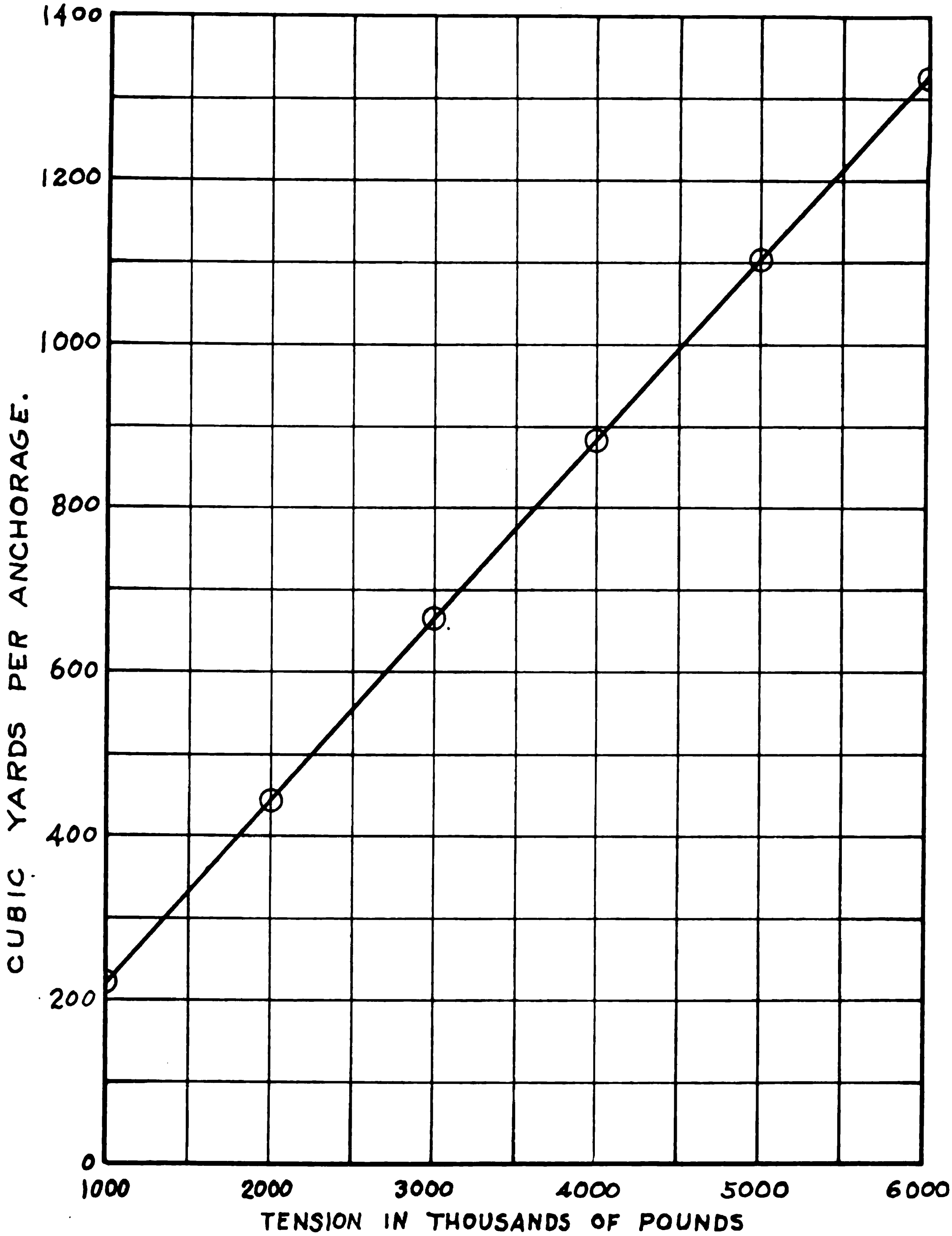
SEE PLATE "E"

CONCRETE PIERS
Plate 16.



PULL ON ANCHORAGE

Plate 17.



CONCRETE IN ANCHORAGE
Plate 18.